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DEVELOPMENT OF MAINTENANCE METRICS TO FORECAST
RESOURCE DEMANDS OF WEAPON SYSTEMS

(FINAL REPORT)

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B-52G	T-38A	Environmental Parameters	Avionics Equipment
FB-111A	LCOM	Equipment Parameters	Multiple Regression
F-15A	METRICS	Computer Simulation	Task Probability
KC-135A	Engines	Difference Analysis	Failure Clock

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the methodology and results of a 32 month effort to "Develop Maintenance Metrics To Forecast Resource Demands of Weapon Systems." Increased concern with the rising cost to support weapon systems currently in operation, as well as those in development, has created the need for more accurate methods of projecting maintenance requirements. The objective of this subject research was to alleviate the above need by identifying, determining, and integrating those measurable weapon system parameters which are necessary and sufficient to predict and quantify the drivers of maintenance resource

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) demands. The study was accomplished in two equal phases. Phase I investigated and developed new maintenance metrics for aircraft propulsion and avionics. Phase I results were then reviewed for overall success and applicability before proceeding with Phase II efforts. Initial results were acceptable so Phase II of the study was initiated to develop metrics for the rest of the subsystems commonly included in Air Force aircraft.

This document is the final report of a series of five technical reports published during the study. The first four were published as Boeing Interim Technical Reports to document the accomplishment of the major study tasks as follows:

D194-10089-1 Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems (Analysis and Evaluation)

Documents all aspects of study data base acquisition and integration.

D194-10089-2 Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems (Parameter Prioritization)

Documents the screening of the data for significant maintenance resource demand drivers.

D194-10089-3 Development of Maintenance Metrics to Forecase Resource Demands of Weapon Systems (Maintenance Metrics and Weightings)

Documents the development of subsystem-specific maintenance demand estimating models from the identified maintenance drivers.

D194-10089-4 Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems (Analysis and Results of Metrics and Weightings)

Documents metrics validation experiments that were performed within the context of the Air Force LCOM simulation system.

This final report is published as a Boeing technical report. It is intended to be a summary overview of the study project and an application guide for potential users of the developed metrics methodology. Study findings contained within include: 1) Review of published literature; 2) Critical equipment selection; 3) Maintenance impact parameter identification; 4) Data base assembly and integration; 5) Maintenance impact estimating relationship detection and analysis; 6) Maintenance metric model development; and 7) Maintenance metrics validation.

SUMMARY

This report describes the results of an eight task study. The effort was intended to develop more accurate metrics and weightings to be incorporated into the Air Force method (Logistics Composite Model (LCOM)) for determining manpower and other resource requirements for operational and developing weapon systems. The eight study tasks comprising this study were as follows:

Task I	Review of Related Research (Boeing document D194-10089-1)
Task II	Select Equipment for Investigation (Boeing document D194-10089-1)
Task III	Identify Parameters for Investigation (Boeing document D194-10089-1)
Task IV	Identify, Obtain, and Integrate Study Data (Boeing document D194-10089-1)
Task V	Analyze and Prioritize Parameters (Boeing document D194-10089-2)
Task VI	Maintenance Metrics Development (Boeing document D194-10089-3)
Task VII	Maintenance Weightings Development (Boeing document D194-10089-3)
Task VIII	Analysis and Modification of Metrics and Weightings (Boeing document D194-10089-4)

PROBLEM

The increased Air Force concern with the rising cost to support weapon systems currently in operation, as well as those in development has created the need for more accurate methods of projecting maintenance requirements. There are two cost driver variables that are generally understood by all. These are the manpower and material or resources to maintain the weapon system. In a recent study conducted on the life cycle cost of the C-130E aircraft (Reference 1) it was determined that labor accounted for 70% of the 15 year cumulative operational and support cost, resources (material) approximately 18%, with the remaining being attributed to fuel and base support. The C-130E experience is typical of the other systems in Air Force inventory.

1 "Life Cycle Cost of C-130E Weapon System" AFHRL-TR-77-46, July 1977.

The major proportion of total operating and support cost incurred for labor and material has developed considerable concern for the manpower and resources required to support weapon systems currently in operation, as well as those in development. A study of maintenance and reliability impact on system support costs (Reference (2)) showed that some 70% of the life cycle cost funds of a new weapon system are essentially committed in the concept phase by initial planning decisions (Figure 1).

This semi-predetermined expenditure has created the need for more accurate methods of projecting maintenance and manpower requirements early in the design process so that trades can be made to reduce long term resource demands. Meeting this need requires the development of realistic predictive measures of maintenance rates for all of the diverse equipment that makes up a weapon system.

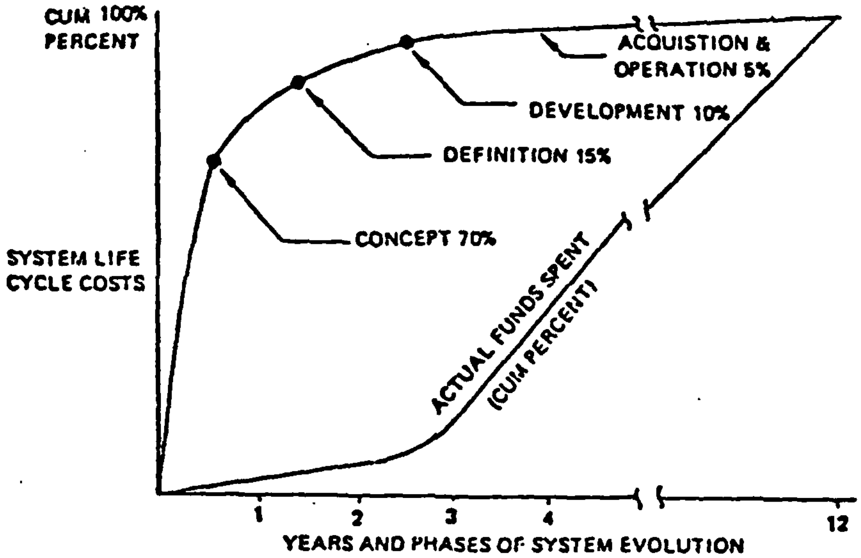

Figure 1 SYSTEMS FUNDS COMMITTED BY INITIAL PLANNING DECISIONS

In addition, the impact of operations and environmental conditions need to be identified to insure the accuracy of the newly developed maintenance metrics under the diverse conditions met by fielded weapon systems.

(2) Maintainability/Reliability Impact on System Support Costs, AFFDL-TR-73-152, December 1973.

To date, the manpower and other resource requirements essential to the operations and support (O&S) of a weapon system have been determined using the traditional "flying hours" and "sortie rate" measures. The deficiencies of these traditional measures are well known and such measures frequently are found to be totally irrelevant (e.g., maintenance on a gun subsystem is generated by factors like the number of rounds fired, and is not affected by the number of flying hours or sorties). These traditional measures are also insensitive to variations in operations and environmental conditions (for example, many avionics equipments may operate or are cycled on the ground greatly in excess of related flying hours or number of sorties). The present difficulties then lie in the fact that the currently used metrics do not consider the inherent differences between the individual subsystems of a weapon system and are relatively insensitive to operational and environmental conditions.

Therefore, the objective of this subject research was to alleviate the above deficiencies by identifying, determining, and integrating those measurable weapon system parameters which are necessary and sufficient to form more accurate metrics and weightings with which to predict system maintenance demands. These metrics and weightings are to be incorporated into the Air Force Logistics Composite Model simulation system.

The LCOM methodology utilizes the simulation capabilities of large digital computers and was evolved to practical use under Project PSM 77-43 (1124), "Human Resources in Aerospace System Development and Operations."

This simulation technology has been documented in a series of technical reports (References 3 through 11), and the technology has been transitioned to the Air Force Management Engineering Agency (AFMEA) with the Air Force Maintenance and Supply Management Engineering Team (AFMSMET) as the office of primary responsibility for the standardization, documentation, maintenance, and further development of the system's master software. The methodology is now being utilized by many other Air Force commands and agencies including Aeronautical Systems Division (ASD/ENCC), Air Force Test and Evaluation Center (AFTEC), Tactical Air Command (TAC), Strategic Air Command (SAC), Military Airlift Command (MAC), United States Air Forces Europe (USAFE), and Pacific Air Forces (PACAF).

3 through 11 See Reference List

APPROACH

The approach taken for this study effort was to identify, obtain, review and catalog a data base consisting of related research findings, and design, operations, maintenance, and environmental data for a selected sample population of aircraft and equipments (study tasks I through IV). This data base was then analyzed for possible causal factors for the expenditure of maintenance resources. These maintenance impacts were structured parametrically and cataloged for future use (task V). The detected maintenance impacts were then combined into mathematical maintenance metric models for each item of equipment studied (tasks VI and VII). These models predict maintenance action demand based on significant design, operational, and environmental factors which impact the maintenance of each equipment item. Validation of the models was performed through testing within the context of LCOM simulations (task VIII).

RESULTS

The results of this study are recorded in the series of four Boeing interim technical reports cited in the task list at the beginning of this summary and in this final AFHRL technical report.

The useful products resulting from the study consisted of: (1) An extensive data base on the common subsystems of Air Force aircraft. This can be used as is for follow-on study and comparability analyses for emerging weapon systems (D194-10089-1, -2, and -3). (3) Maintenance metric mathematical models for 30 common aircraft subsystems (D194-10089-3 and Final -5). These models are useful for maintenance resource expenditure predictions for new aircraft equipment, new basing concepts, new operational scenarios, and LCOM simulation studies. (4) Trial LCOM validation experiments using the new metrics which demonstrate the methodology and provide confidence measures for future users (D194-10089-4 and Final -5).

PREFACE

This technical report is the last in a series of five technical reports under Phase I and II of Contract No. F33615-77-C-0075, Development of Maintenance METRICS To Forecast Resource Demands of Weapon Systems:

Interim Report I:	Boeing Document D194-10089-1, Analysis and Evaluation
Interim Report II:	Boeing Document D194-10089-2, Parameter Prioritization
Interim Report III:	Boeing Document D194-10089-3, Maintenance Metrics and Weightings
Interim Report IV:	Boeing Document D194-10089-4, Analysis and Results of Metrics and Weightings
Final Report:	Development of Maintenance Metrics To Forecast Resource Demands of Weapon Systems, D194-10089-5

Interim Reports I, II, III, and IV are published as Boeing Aerospace Company reports and are filed with the government's Defense Technical Information Center (DTIC).

Data emanating from this contract, "Development of Maintenance METRICS To Forecast Resource Demands of Weapon Systems," are reported in the above series of four Boeing interim technical reports and this AFHRL final technical report. Phase I of the study provided the identification of aircraft avionic and engine maintenance resource demands, design characteristics, operational factors, maintenance factors, and environmental factors which were used to develop more accurate metrics and weightings for incorporation into the Air Force Logistics Composite Model (LCOM). Phase II of the study provides metrics and weightings for the rest of the subsystems making up a typical Air Force aircraft. A contract addition provided for additional metrics LCOM validation experiments to demonstrate the accuracy and utility of the developed methodology.

This approved final technical report (TR) includes work performed from 1 March 1978 through 30 October 1980.

This study contract was performed by the Boeing Aerospace Company Product Support/Experience Analysis Center (PS/EAC), Seattle, Washington. USAF Contract F33615-77-C-0075 was initiated under Exploratory Development Area PMS 77-43 (1124). Work was accomplished under the direction of the Logistics Research Division of the Air Force Human Resources Laboratory, Air Force Systems Command with Mr. Frank Maher as the Work Unit Scientist and Air Force Contract Monitor.

Experience Analysis Center program technical leader was George R. Herrold. Principal program analysts were Donald K. Hindes, Gary A. Walker, and David H. Wilson.

The Boeing Aerospace Company wishes to express their appreciation for the technical assistance and data provided by: a) AFLC Headquarters, Aeronautical Systems Division, and Air Force Maintenance and Supply Management Engineering Team, Wright-Patterson AFB, Ohio, b) Air Weather Service (MAC) Environmental Technical Applications Center and Military Airlift Command Headquarters, Scott AFB, Illinois, c) Air Force Europe Headquarters, Ramstein AB, Germany, d) Air Training Command Headquarters, Randolph AFB, Texas, e) Strategic Air Command Headquarters, Offutt AFB, Nebraska, f) Tactical Air Command Headquarters, Langley AFB, Virginia, g) 12th FTW, Randolph AFB, Texas, h) 36th TFW, Bitburg AB, Germany, i) 58th TTW, Luke AFB, Arizona, j) 60th MAW, Travis AFB, California, k) 92nd BMW, Fairchild AFB, Washington, l) 35th TFW, Myrtle Beach AFB, South Carolina, m) 355th TFW, Davis-Monthan AFB, Arizona, and n) 380th BMW, Plattsburgh AFB, New York.

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1.0 INTRODUCTION

The following is a brief overview of the eight major tasks required to accomplish this study. Figure 2 shows the relationships of these tasks and Figure 3 indicates the study products resulting from the accomplishment of each task.

TASK I — Identify, Obtain, and Review Related Publications
- review related studies and research dealing with maintenance rates and causes.

TASK II — Select Equipment
- develop matrices of equipment by aircraft type in order to select specific hardware subsystems and equipments.

TASK III — Identify Parameters
- identify maintenance, hardware, operational environmental, and aircraft general parameters which would have an impact on maintenance for the subject subsystems.

TASK IV — Identify and Integrate Data Sources
- identify, assemble, correlate, and integrate the data base on the equipment selected in Task II for the related parameters being considered in Task III.

TASK V — Analyzing and Prioritizing Parameters
- analyze the collected data to define and test relationships between the study parameters and maintenance demand rates.

TASK VI — Maintenance Metrics Development
- develop metrics for quantifying maintenance demand rates which are computable with LCOM models.

TASK VII — Maintenance Weightings Development
- develop weightings, quantifying identified operational and environmental impacts upon maintenance demand rates, and combine with the metrics developed in Task VI.

TASK VIII — Analysis and Modification
- analyze LCOM model outputs which compare current practice with the newly developed metrics and weightings to illustrate the relative accuracy and confidence that may be expected when using the new metrics.

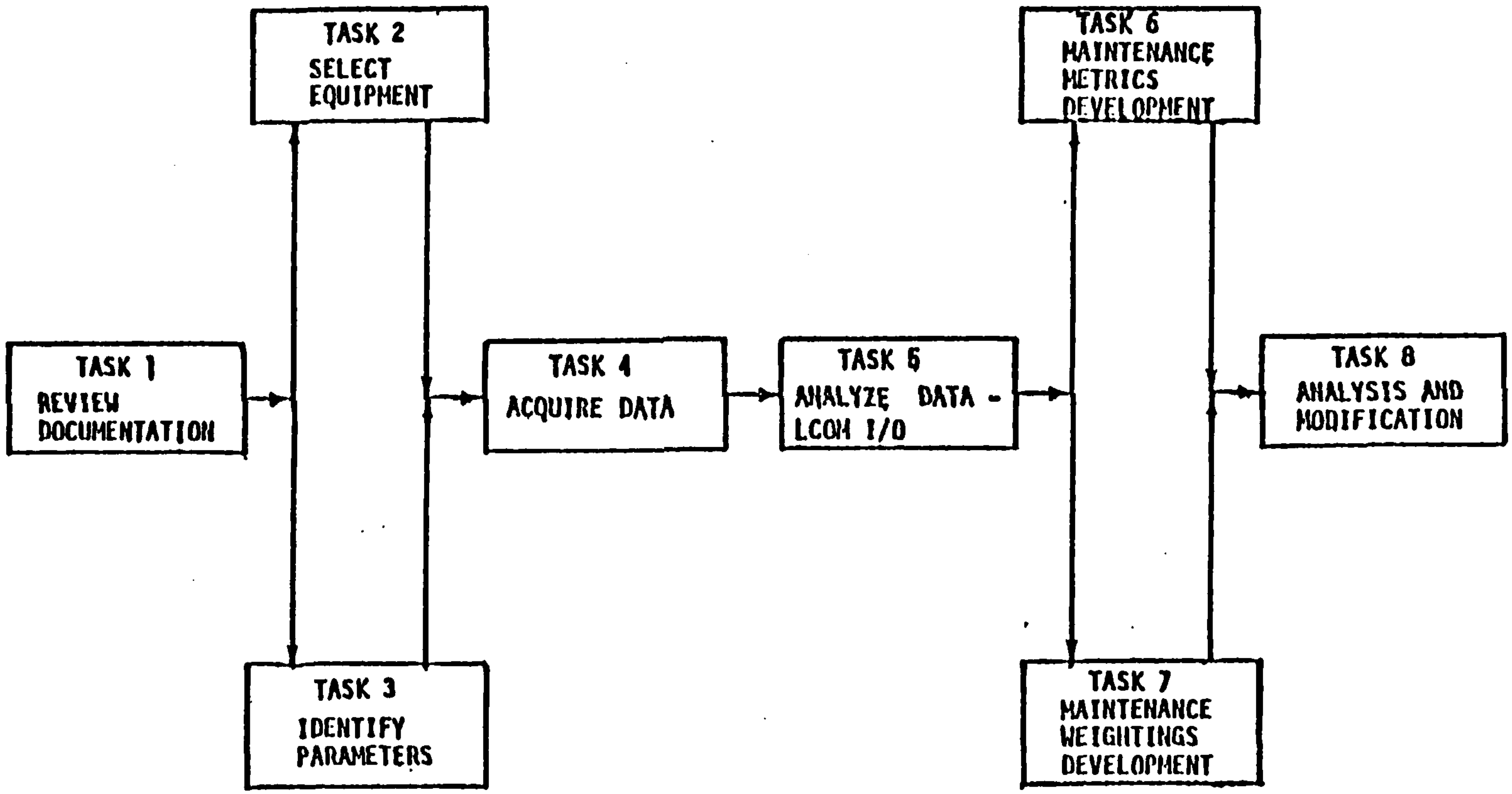


FIGURE 2 STUDY TASKS FLOW DIAGRAM

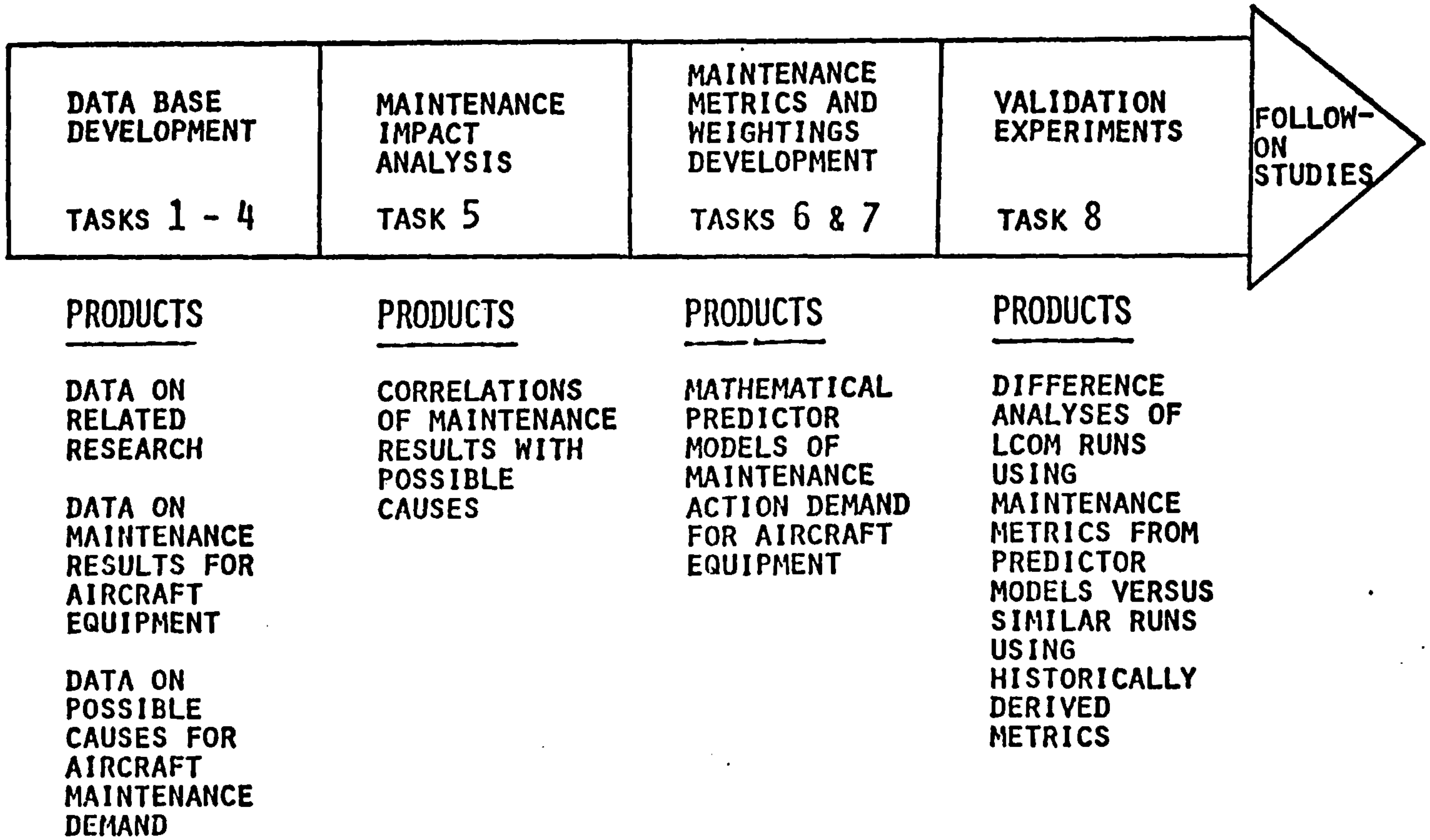


FIGURE 3 STUDY ACTIVITIES AND PRODUCTS BY MAJOR TASKS

Task I is discussed in Section 2.0 of this report. Task II, Task III, Task IV, and Task V are discussed in Sections 3.0, 4.0, 5.0, and 6.0 respectively. Tasks VI and VII are covered in Section 7.0. Task VIII is covered in Section 8.0 while Section 9.0 presents the major findings, conclusions, and recommendations which emerged from the study. Selected detail instruments and products of the various tasks which would be useful to users of the methodology are included as appendices.

2.0 IDENTIFY, OBTAIN, AND REVIEW RELATED PUBLICATIONS - TASK I

The initial step undertaken in this study was to establish a method by which to identify, obtain, and review applicable literature. The related research and/or descriptive studies covering aircraft weapon system maintenance causes and measures/rate of occurrences was constrained to those published within the last ten years. This task was accomplished along typical steps and/or analytical sequences normally performed when conducting a data review. The five major steps, as depicted in Figure 4, were:

a) STINFO Search
b) Screen Indexes
c) Review Literature
d) Catalog Selected Items
e) Develop Bibliography

The results of this process are depicted in Figure 5 and may be summarized as follows. The STINFO search produced over 1200 abstracts that were screened to 300 documents for acquisition and further study. These then resulted in a METRICS Historical File and a Bibliography of over 100 pertinent contributors to the study. Complete details and data pertaining to Task I study efforts are contained in Boeing Interim Technical Report D194-10089-1 (Reference [12]). The significant finding of this task effort was that no studies have been done within the last ten years which attempted to duplicate the objective of the maintenance metrics study, or which utilized methodology which was directly applicable to this study. The bibliography is useful, however, as a source of historical "lessons learned" data and as source material for future follow-on studies, and as the principle source of maintenance impact parameters identified during the course of Study Task III (See Section 4.0).

[12] "Development of Maintenance Metrics to Forecast Resource Demands Of Weapon Systems (Analysis and Evaluation) D194-10089-1, June 1979.

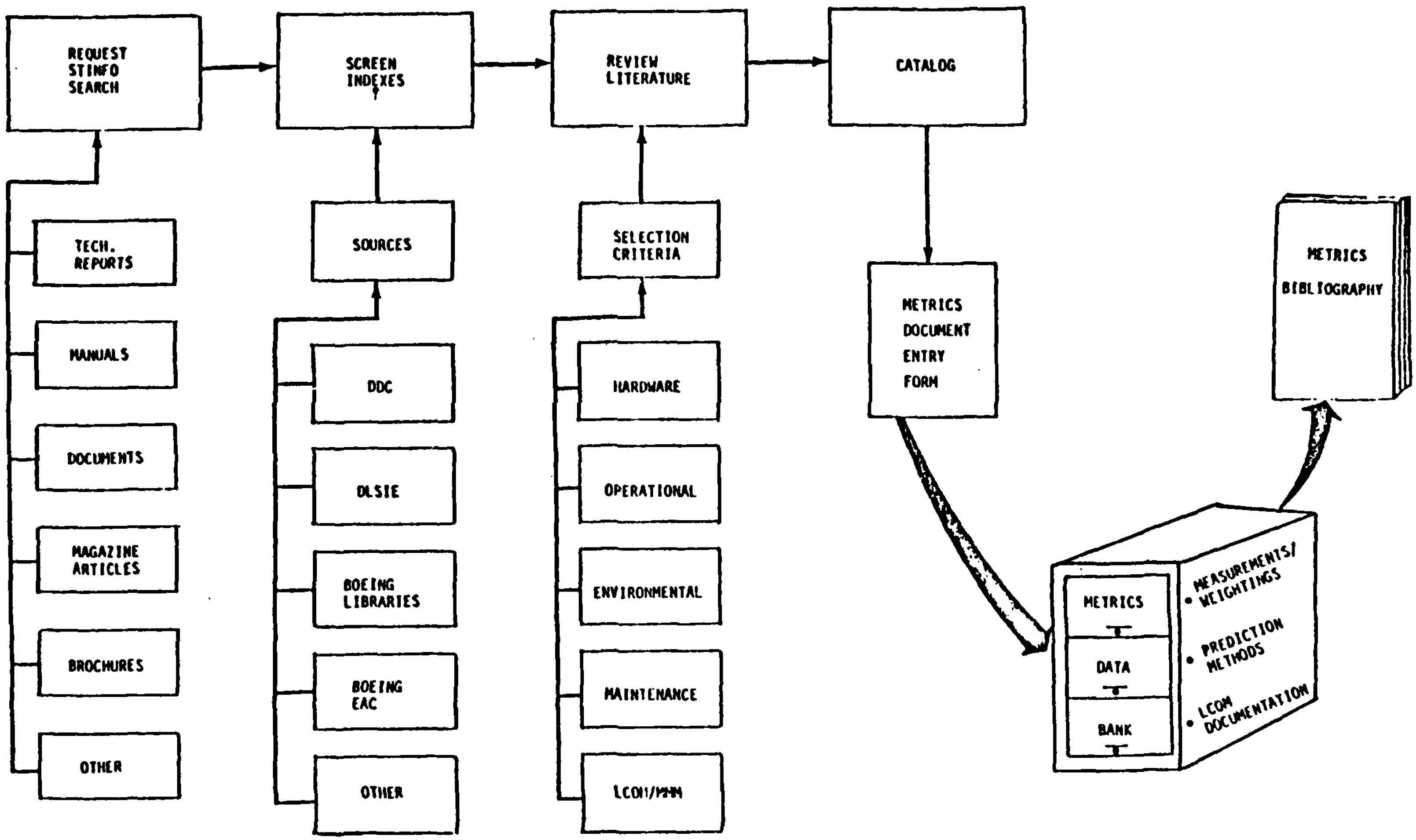


FIGURE 4 IDENTIFY, OBTAIN, AND REVIEW RELATED PUBLICATION FLOW - TASK 1

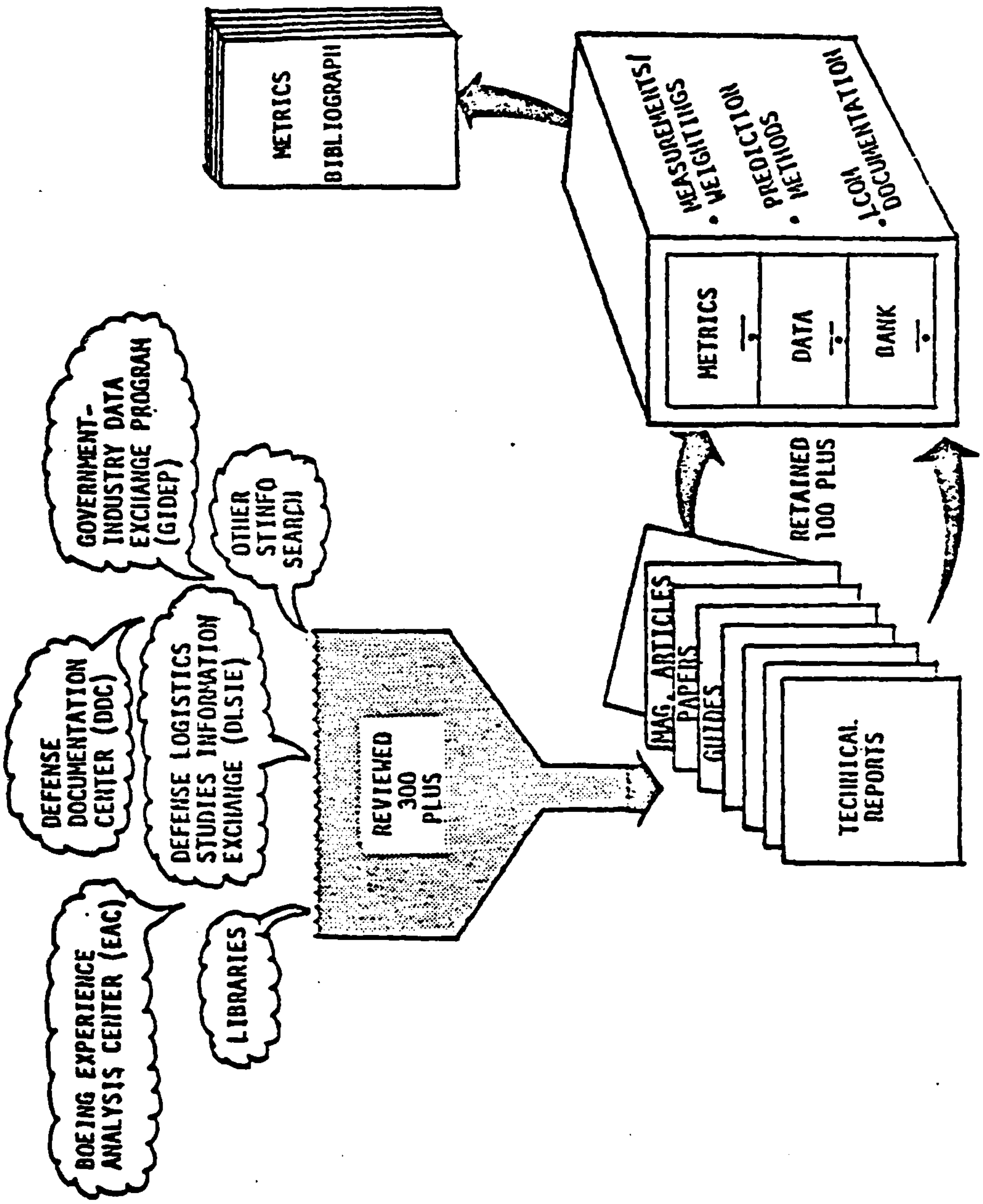


FIGURE 5 SUMMARY OF TASK I

2.1 STINFO SEARCH

The STINFO Search was conducted through the Boeing Aerospace Technical Library which has the capability of searching, effectively and efficiently, other technical libraries, data banks, and information repositories. The search was keyed via descriptive words that most aptly conveyed the objectives of this study. Any and all media, i.e., technical reports, manuals, etc. were considered for review.

2.2 SCREEN INDEXES

The products of the STINFO Search were in the form of computer listings and other types of indexes. These emanated from such repositories as DDC, DLSIE, etc. which then had to be screened, via the report title and abstract, and acquired if they appeared to have direct application to the study. Over 1200 such abstracts were reviewed which resulted in approximately 300 documents being selected as likely contributing candidates.

2.3 REVIEW LITERATURE

The information was then divided into five major categories; i.e., maintenance, hardware (equipment), operational, environmental, and aircraft general. Only documents that were aircraft weapon system maintenance cause and measure/rate oriented were included in each of these categories. Also if data on LCOM/MMM was contained in the report, it was retained. Although the primary equipment areas for this phase of the study were engines and avionics, information on the remaining aircraft systems was identified and cataloged in preparation for Phase II. Over 100 reports passed this screen. For simplicity all historical information, regardless of form, will be henceforth referred to as a document.

An interesting fact emerged from this literature search in that no published documents were similar or duplicated the work being done in this study.

2.4 CATALOGING

To aid in the retention and subsequent retrieval of the documents for analysis in future tasks, a computerized log form was developed. This form, Figure A-1, located in Appendix "A," not only provided a systematic method of building the METRICS Data File but it allowed the investigators to more efficiently screen and identify the useful content of a given document that may be required in an analysis task. More than 300 documents were reviewed in this manner.

A total of seventeen fields are available on the log form for coding/indexing the pertinent factors of a document to describe its characteristics. Descriptions of these fields are also included in Appendix "A."

2.5 BIBLIOGRAPHY

As mentioned in 2.3 above, approximately one hundred documents were screened out and assembled into the Maintenance Metrics Reference File to serve as a source of "lessons learned," candidate maintenance impact parameters, and source data for follow-on studies. The contents of this file are accessible through the reference bibliography contained in Boeing Interim Technical Report D194-10089-1 (Reference 12).

3.0 SUBSYSTEM EQUIPMENT SELECTION - TASK II

In order to scope the study aircraft and subsystem equipment selection to the resources and time available for the study, an examination of the subsystem equipment configurations was made across a representative population of current Air Force aircraft. This examination was limited to Air Force aircraft currently in the inventory for which current operational data was available or could be obtained from on-site visits. The subsystem equipment selection task was divided into a set of sub-tasks sequentially organized as presented in Figure 6. The following subsections detail the approach and subsystem equipment selection process.

The subsystem/equipment selection process resulted in the selection of seven study aircraft, 30 standard aircraft subsystems, and 463 representative equipment items within these subsystems. These equipments were used as the subjects of the parametric maintenance resource demand follow-on analysis. They were selected to represent a wide variation in equipment types, design technology, parts size, complexity, maturity states, usage in different aircraft/mission types and operational and environmental conditions. Complete details and data pertaining to Task II study efforts are contained in Boeing Interim Technical Report D194-10089-1 (Reference 12).

3.1 IDENTIFY STUDY AIRCRAFT

A preliminary list of candidate aircraft was compiled considering the following criteria:

a) Representative aircraft of various types currently in the Air Force inventory, i.e., bomber, cargo/transport, fighter, trainer, and attack.

b) Wide range of operational commands (usage) and different environments represented by selected aircraft, i.e., different missions and operating locations across various types of aircraft.

c) Wide range of avionic subsystems and engine applications with different complexity, packaging, and maturity represented within the selected aircraft.

d) Sufficient data sample size available for credible analysis.

The list of candidate aircraft originally compiled consisted of 14 different types of aircraft at over 30 locations, and after applying the above mentioned aircraft selection criteria the list was narrowed down to seven different types of aircraft at nine locations. Table 1 presents the selected aircraft in terms of aircraft type, model, series, and the selection criteria discussed above.

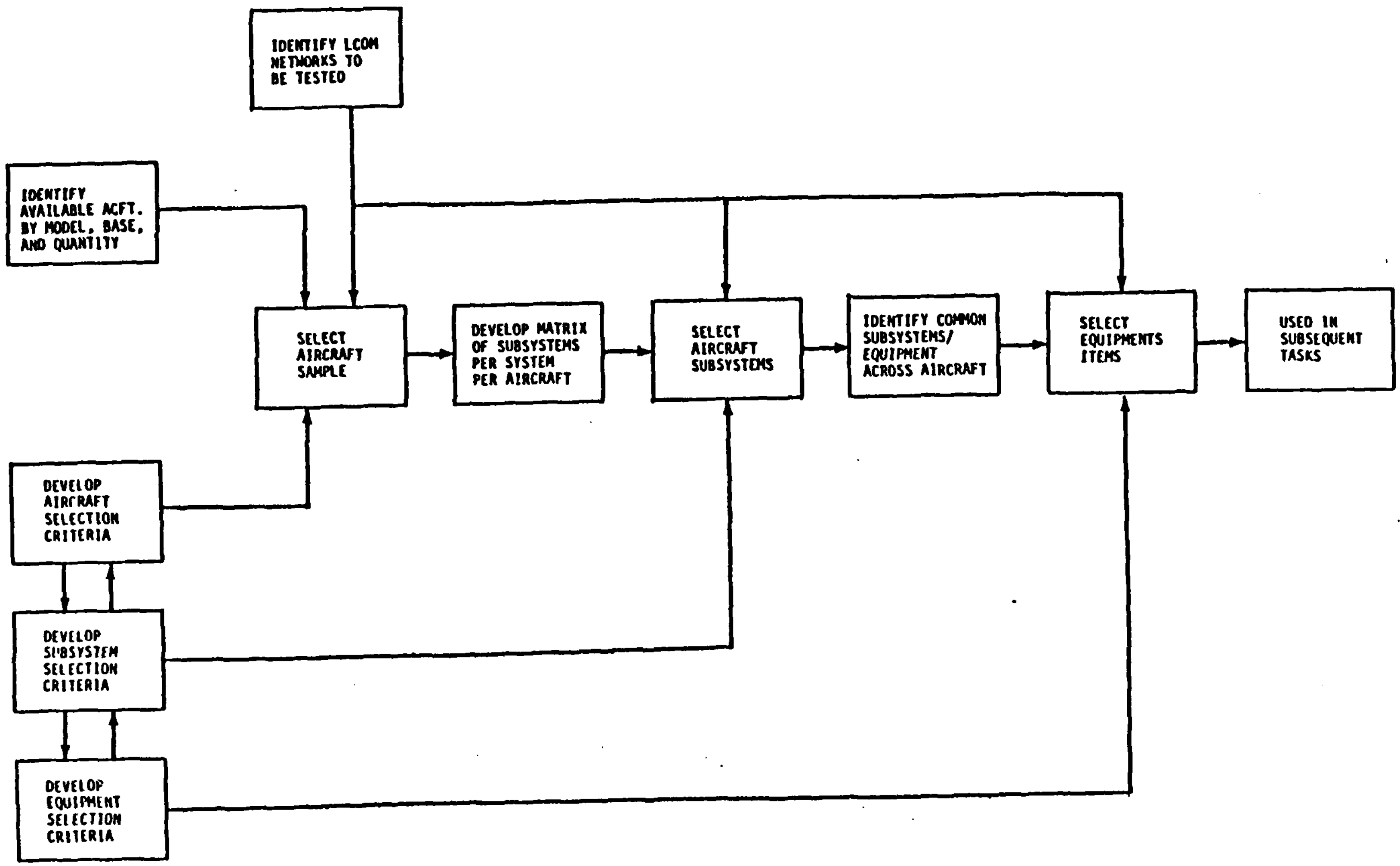


FIGURE 6 TASK II - SUBSYSTEM EQUIPMENT SELECTION ACTIVITY FLOW

TABLE 1 STUDY AIRCRAFT/AIR FORCE BASES

AIRCRAFT					GEOGRAPHIC LOCATION					PRIMARY WX ENVIRON.				
TYPE	MDS	QTY	COMMAND	BASE	NORTH	SOUTH	EAST	WEST	EUROPE	HOT	COLD	HUMID	DRY	TYPE ENGINE
BOMBER	B-52G	16	SAC	FAIRCHILD WA	X			X			X		X	J57
BOMBER	FB-111A	31	SAC	PLATTSBURGH NY	X		X				X			TF30
CARGO	C-141A	35	MAC	TRAVIS CAL				X		X		X		TF33
TANKER	KC-135A	27	SAC	FAIRCHILD WA	X			X			X		X	J57
FIGHTER	F-15A	43	TAC	LUKE ARIZ		X		X		X			X	F100
FIGHTER	F-15A	70	AFE	BITBURG GERMANY					X		X	X		F100
ATTACK	A-10A	31	TAC	MYRTLE BEACH SC		X	X			X		X		TF34
ATTACK	A-10A	19	TAC	DAVIS-MONTHAN ARZ		X		X		X			X	TF34
TRAINER	T-38	75	ATC	RANDOLPH TEX		X				X		X		J85

3.2 DEVELOP SUBSYSTEM/EQUIPMENT SELECTION CRITERIA

The initial subsystem equipment selection criteria were developed early in the study and were expanded during the accomplishment of Task I Literature Review. The selection criteria utilized during the actual subsystem equipment selection process are as follows:

a) Equipment selected should be functionally representative of a wide cross-section of aircraft applications and use environments.

b) Equipment selected should represent a wide variation in type, i.e., design technology (new-old), electrical/mechanical, parts count/complexity, maturity states, testability, and usage.

c) Packaging and design technology must be projectable into the future to prevent obsolete technology from unduly biasing statistical relationships which will be used for future predictions.

d) Equipment must be mature enough for data samples to be taken beyond the learning curve period, yet include relatively new and old equipment.

e) Equipment must have a statistically valid population of operational units in use.

f) The equipment must have sufficient historical data available for valid analysis.

g) Equipment selected should represent a significant percentage of the total maintenance resources expenditure demands, i.e., maintenance manhours, failures, removals, costs, etc.

h) Equipment should be of a nature for which factors other than just flying hours may contribute to their reliability/maintainability characteristics.

i) Equipment selected should fit within the functional grouping of the LCOM network to be utilized during Task VIII - Analysis and Modification.

3.3 IDENTIFY SUBSYSTEM/EQUIPMENT APPLICATIONS BY TYPE AIRCRAFT

The next logical process was to develop an aircraft versus subsystem application matrix identifying the aircraft subsystems. This was accomplished by detail review of each system in the applicable aircraft work unit code (-06) technical orders. Six hundred sixty three individual equipment items were examined during this review.

3.4 SELECT SUBSYSTEM EQUIPMENTS

Prior to selection of the study subsystem equipments, it was necessary to review the LCOM networks available on the seven study aircraft and determine which aircraft/LCOM networks would be utilized to perform Task VIII - Analysis and Evaluation effort. This was necessary to insure that selected equipments would fit functionally within the subsystem structure of the LCOM network to be utilized. This review and coordination with the AFHRL contract monitor resulted in selection of the Tactical Air Command (TAC) F-15A LCOM network as the baseline configuration.

Utilizing the 663 equipments identified above, the following sequential step by step subsystem equipment selection process was accomplished:

a) First, in order to reduce the large amount (663) of equipment items down to a manageable number for the study, those systems/subsystems that showed up on less than five of the seven study aircraft were eliminated.

b) Identified all F-15A subsystems contained in the TAC F-15A LCOM network.

c) Identified the functionally equivalent subsystems or similar equipment groupings within the other six study aircraft.

d) Identified and listed all work unit codes (at the four or five digit level as appropriate) for each of the subsystem/equipment functional groupings identified in b and c above.

e) Determined the number of failures reported against each of the work unit codes within each of the subsystem functional groupings from b and c above.

f) Totaled the number of failures within each subsystem functional groupings and computed what percentage of the subsystem functional grouping total the failures for each work unit code represented.

g) Selected the work unit code(s) within each subsystem functional grouping on each aircraft that represented the top failure percentage (50% or greater) of the total failures within the subsystem.

h) Compared common functions of the subsystem equipments selected on each aircraft and made minor adjustments as necessary to insure that functional equivalent or similar subsystem equipments were selected across each study aircraft.

Table 2 depicts the subsystems/functional groupings of equipment items selected across the seven study aircraft arrayed by each study phase. As reflected in Table 2, all of the engine subsystems were rolled up to the two digit level of the work unit code structure and the complete propulsion system is considered as one equipment item on each aircraft. This was necessary as the F-15A LCOM network is structured utilizing the same process. All other subsystem equipments on all seven aircraft are structured at the work unit code three digit level or lower (four or five digit level).

TABLE 2 SELECTED EQUIPMENTS ARRAYED BY STUDY PHASE

PHASE 1 SYSTEMS	PHASE 1 EQUIPMENTS	PHASE 2 SYSTEMS	PHASE 2 EQUIPMENTS
• PROPULSION	- COMPLETE ENGINES	• AIRFRAME	- RADOMES WINDSHIELDS WINGS
• INSTRUMENTS	- FLIGHT INDICATORS	• COCKPIT FURNISHINGS	- CREW SEATS
• AIR DATA SYSTEM	- COMPUTERS TRANSMITTERS	• LANDING GEAR	- WHEELS TIRES BRAKES
• HORIZONTAL SITUATION INDICATOR	- INDICATORS COMPUTERS	• FLIGHT CONTROLS	- STABILATORS RUDDERS FLAPS
• AUTOPILOT	- COMPUTERS AMPLIFIERS	• ENVIRONMENTAL CONTROL	- WATER SEPARATORS
• UHF COMMUNICATION SET	- R/T UNITS	• ELECTRICAL POWER	- GENERATORS
• IFF SET	- R/T UNITS COMPUTERS	• LIGHTING	- NAVIGATION LIGHTS ANTI-COLLISION LIGHTS LANDING/TAXI LIGHTS
• INERTIAL NAVIGATION	- INERTIAL MEAS. UNIT COMPUTERS	• HYDRAULIC POWER	- PUMPS
• INSTRUMENT LANDING SET	- RECEIVERS	• INTERNAL FUEL	- TANKS
• TACAN SET	- R/T UNITS	• CREW OXYGEN	- OXYGEN RGULATORS LOX CONVERTERS
• ATTITUDE-HEADING REF. SET	- GYROSCOPES AMPLIFIERS	• MISCELLANEOUS	- FIRE DETECTION SENSORS
• RADAR SET	- R/T UNITS SYCHRONIZERS DISPLAYS		

4.0 PARAMETER IDENTIFICATION - TASK III

The identification and screening process for potential maintenance resource demand (MRD) and maintenance impact parameters associated with the selected subsystems/equipments is depicted in Figure 7. The identification and selection of appropriate parameters or variables required detailed review of the various parameters and variables identified in other related studies to determine usefulness, types of input variables required, source, and availability of the necessary input data. The documentation file assembled during Task I (Section 2.0) was utilized for this purpose.

The parameter identification task resulted in 193 significant and collectable parameters being selected for use in the follow-on study tasks. Complete details including a list of the study parameters selected and their data values pertaining to Task III and IV study efforts are contained in Boeing Interim Technical Report D194-10089-1 (Reference 12).

4.1 PARAMETER IDENTIFICATION

The investigation and identification of appropriate parameters relied heavily upon the previous work conducted during Task I - "Review of Related Publications" (Section 2.0) and Task II - "Subsystem Equipment Selections" (Section 3.0). These related study documents were reviewed and all potential study parameters identified for each of the following six major categories: (1) maintenance resource demands, (2) operational, (3) maintenance, (4) environmental, (5) hardware/equipment (subdivided into avionics, engine, and other), and (6) aircraft general.

4.2 PARAMETER SELECTION

During the parameter investigation and identification process, all possible parameters or variables were identified and categorized into the six major categories discussed above. The parameter selection process was then based on selecting only those parameters or variables that passed the selection criteria as follows:

a) Useful - The parameter or variables had to have a possibility of being sensitive to the maintenance resource demand requirements of the subsystem(s)/equipments that were being studied;

b) Source of Information - There had to be an identifiable source of information required for the parameter or variables; and

c) Availability of Information - The necessary information for use of the parameter or variables had to be available to the study team based on need to know requirements.

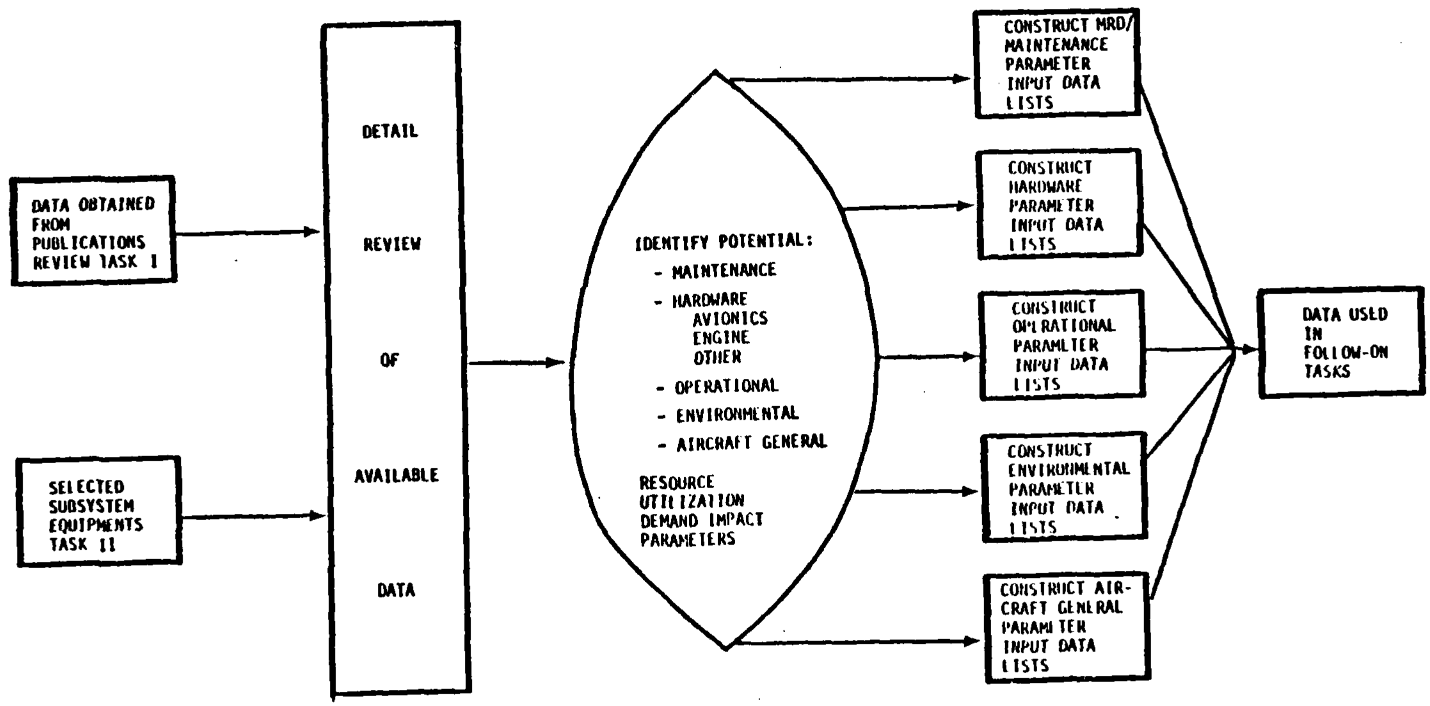


FIGURE 7 - TASK III PARAMETER IDENTIFICATION ACTIVITY FLOW

Based on the above selection criteria, a total of 193 individual parameters were selected within the six major categories. Tables 3 through 10 list the parameters in each of these categories. Table 3 is a list of dependent maintenance resource demands. Tables 4 through 10 are lists of independent parameters in the various categories which were selected as candidate maintenance impact parameters.

TABLE 3 MAINTENANCE RESOURCE DEMAND (MRD) PARAMETERS

Variable I.D. Number	Label Name
R01	Maintenance Action Demand per Aircraft
R02	Equipment Total Maintenance Manhour per Aircraft
R03	Equipment Total Unscheduled Removals per Aircraft
R04	Equipment Ground Aborts per Aircraft
R05	Equipment Air Aborts per Aircraft
R06	Equipment Cannibilizations per Aircraft

TABLE 4 OPERATIONAL PARAMETERS

Variable I.D. Number	Label Name
001	Maintenance Action Demand per Aircraft
002	Years Aircraft Have Been on Base
003	Average Mission Mix
004	Aircraft Grounded Time
005	Average Take-Off Speed
006	Median Take-Off Distance
007	Percent of Maximum Take-Off Weight
008	Average Climb Rate
009	Average Cruise Speed
010	Average Cruise Altitude
011	Average Descent Rate
012	Average Landing Speed
013	Minimum Landing Distance
014	Average Landing Weight
015	Total Flying Hours per Aircraft
016	Training Flying Hours per Aircraft
017	Operations Flying Hours per Aircraft
018	Misc. Flying Hours per Aircraft
019	Total Landings per Aircraft
020	Training Landings per Aircraft
021	Operations Landings per Aircraft
022	Misc. Landings per Aircraft
023	Average Number of Aircraft on Alert
024	Average Number of Deployed Aircraft
025	Total Sorties per Aircraft
026	Training Sorties per Aircraft
027	Operations Sorties per Aircraft
028	Misc. Sorties per Aircraft
029	Average Possessed Aircraft
030	Maximum Aircraft Speed
031	Maximum Aircraft Ceiling
032	Aircraft Crew Size
033	Average Sortie Length
034	Accidents (Major/Minor) per Aircraft
035	Incidents per Aircraft

TABLE 5 MAINTENANCE PARAMETERS

Variable I.D. Number	Label Name
M01	Maintenance Action Demand per Aircraft
M02	Average OR Rate
M03	Average NORM Rate
M04	Average NORS Rate
M05	Total Maintenance Personnel Authorized
M06	Total Maintenance Personnel Assigned
M07	Total 3 Level Maintenance Personnel Assigned
M08	Total 5 Level Maintenance Personnel Assigned
M09	Total 7 Level Maintenance Personnel Assigned
M10	Total 9 Level Maintenance Personnel Assigned
M11	Total Maintenance Personnel Authorized (AMS)
M12	Total Maintenance Personnel Assigned (AMS)
M13	Total 3 Level Maintenance Personnel Assigned (AMS)
M14	Total 5 Level Maintenance Personnel Assigned (AMS)
M15	Total 7 Level Maintenance Personnel Assigned (AMS)
M16	Total 9 Level Maintenance Personnel Assigned (AMS)
M17	Total Maintenance Manhours Expended per Aircraft
M18	AMS Maintenance Manhours Expended per Aircraft
M19	Maintenance Concept
M20	Average Turn-Around Time - Maintenance
M21	Aircraft FOD (All Causes)
M22	Total General Support (01-09) Manhours per Aircraft
M23	Total General Support - 01 Manhours per Aircraft Ground Handling and Servicing
M24	Total General Support - 02 Manhours per Aircraft Aircraft Cleaning
M25	Total General Support - 03 Manhours per Aircraft Look Phase of Scheduled Inspections
M26	Total General Support - 04 Manhours per Aircraft Special Inspections
M27	Total General Support - 05 Manhours per Aircraft Preservation and Storage
M28	Total General Support - 06 Manhours per Aircraft Arming and Disarming
M29	Total General Support - 07 Manhours per Aircraft Preparation and Maintenance of Records
M30	Total General Support - 09 Manours per Aircraft In-Shop General Support

TABLE 6 ENVIRONMENTAL PARAMETERS

Variable I.D. Number	Label Name
E01	Maintenance Action Demand per Aircraft
E02	Base Altitude
E03	Runway Direction
E04	Distance to Mountains
E05	Direction of Mountains
E06	Number of Snow Days
E07	Total Snow Fall
E08	Mean Snow Depth
E09	Number of Rain Days
E10	Total Rain Fall
E11	Number of Hail Days
E12	Relative Humidity (Average)
E13	Number of Thunder Days
E14	Number of Sleet Days
E15	Number of Fog Days
E16	Predominate Wind Direction
E17	Maximum Crosswind's Less Than 10 MPH
E18	Maximum Crosswind's 10-19 MPH
E19	Maximum Crosswind's 20-29 MPH
E20	Maximum Crosswind's 30-39 MPH
E21	Maximum Crosswind's 40-49 MPH
E22	Maximum Crosswind's Greater Than 50 MPH
E23	Mean Temperature
E24	Mean Minimum Temperature
E25	Mean Maximum Temperature
E26	Days Maximum Temperature was Above 80° "F"
E27	Days Minimum Temperature was Below 32° "F"
E28	Total Number of Obstructions to Vision
E29	Predominate Type of Obstructions
E30	Average Obstruction Type
E31	Average Obstruction Severity

TABLE 7 AVIONICS PARAMETERS

Variable I.D. Number	Label Name
A01	Maintenance Action Demand per Aircraft
A02	Equipment Location on Aircraft
A03	Equipment Weight
A04	Equipment Volume
A05	SRU Count
A06	Operating Temperature
A07	Cooling Method
A08	Protection Devices
A09	Number of Test Points (Org. Level)
A10	Required Age
A11	Age Availability
A12	Age Unreliability
A13	Average Operating Time per Sortie
A14	Failure/Malfunction Causes
A15	Retest OK Rate
A16	On-Off Cycles per Flying Hour
A17	On-Off Cycles per Sortie
A18	Ground/Flight Operating Ratio
A19	Failure/Abort Ratio
A20	Equipment Density
A21	Equipment Total Maintenance Manhour per Aircraft
A22	Equipment Total Removals per Aircraft
A23	Equipment Unscheduled Removals per Aircraft
A24	Equipment Scheduled Removals per Aircraft
A25	Equipment Ground Aborts per Aircraft
A26	Equipment Air Aborts per Aircraft
A27	Equipment Cannibilizations per Aircraft

TABLE 8 ENGINE PARAMETERS

Variable I.D. Number	Label Name
P01	Maintenance Action Demand per Aircraft
P02	Total Number of Installed Engines
P03	Take-Off Thrust per Engine
P04	Weight per Engine
P05	Volume per Engine
P06	Density per Engine
P07	Number Compressor Sections per Engine
P08	Number Compressor Blades per Engine
P09	Turbine Section Size
P10	Maximum Engine Combustion Temperature
P11	Maximum Engine Fuel Flow
P12	Minimum Engine Fuel Flow
P13	Engine Prime Depot
P14	Engine Age Availability
P15	Engine Age Unreliability
P16	Engine Vibration Factors
P17	Total Maintenance Manhours per Installed Engine
P18	Total Engine Maintenance Manhours per Aircraft
P19	Total Engine Removals per Aircraft
P20	Unscheduled Engine Removals per Aircraft
P21	Scheduled Engine Removals per Aircraft
P22	Engine Ground Aborts per Aircraft
P23	Engine Air Aborts per Aircraft
P24	Engine Parts Cannibilization per Aircraft

TABLE 9 OTHER EQUIPMENT PARAMETERS

Variable I.D. Number	Label Name
F01	Location of Equipment on the Aircraft
F02	Primary Material - Composition Technology Level
F03	Equipment Weight
F04	Equipment Volume
F05	Operating Temperature
F06	Support Equipment Complexity
F07	Support Equipment Reliability
F08	Type of Failure Problems
F09	Inflight Squawk Verification Rate
F10	On/Off Cycles per Sortie
F11	Ground to Flight Operating Ratio
F12	Relative Reliability of Equipment Driving Force
F13	Removals to Access Other Equipment
F14	Severity of FOD
F15	Principle Failure Cause
F16	Equipment Protection Methodology
F17	Equipment Pressurization Level
F18	Rain Removal Technology (Windshield)
F19	Mounting Position
F20	Power Rating (Generators)
F21	Number of Tire Ply's (Tires)
F22	Landings per Tire (Tires)
F23	Average Tire Cost (Tires)
F24	Securing Method Technology

TABLE 10 AIRCRAFT GENERAL PARAMETERS

Variable I.D. Number	Label Name
G01	Maintenance Action Demand per Aircraft
G02	Years Since Aircraft was Produced
G03	Aircraft Empty Weight
G04	Maximum Gross Weight - Take-Off
G05	Aircraft Wing Area
G06	Aircraft Aspect Ratio
G07	Total Fuel Capacity
G08	Average Aircraft Wing Load
G09	Years Since Engine Production
G10	Number of Installed Engines per Aircraft
G11	Engine Weight per Aircraft (All Engines)
G12	Total Thrust per Aircraft
G13	Designated Climb Rate
G14	Number of Generator's per Aircraft
G15	Total Maintenance Manhour per Flight Hour
G16	Years Since Aircraft First Flight

5.0 IDENTIFICATION AND INTEGRATION OF DATA SOURCES - TASK IV

This task, data base development, was critical to the quality and credibility of the study. Without adequate and correct data for the 193 study parameters identified in Task III (Section 4.0), the remaining tasks would be less meaningful as would any analysis effort that employed statistics and a computer model. Therefore, additional emphasis was placed on this task to insure the accomplishment of the objectives.

The total task was logically divided into three distinct sub-tasks; a) Identification, b) Acquisition, and c) Integration. Figure 8 depicts the step-by-step functional flow developed and the sub-indentures of each step.

The study data base assembled by this task effort consisted of nine sample data values (one for each aircraft/base combination selected in Task II) for each equipment related parameter (81 in all) for each of the 30 equipment subsystems studied (21,870 data entries). Nine data cases were also obtained for each of the non-equipment study parameters such as operational and environmental. There are 112 of these parameters so the resultant data base contains 1008 data entries in the non-equipment categories.

In order to obtain and assemble the above data base, over seven million maintenance transactions (records) were obtained from nine different data systems and over 400 supplemental data parameters acquired directly from on-site visits to eight operational bases. AFM 66-1 (D056E) data for seven aircraft was processed per LCOM criteria into easily readable multi-WUC-digit formats in preparation for follow-on detail analysis. Complete details and data pertaining to Task IV study efforts are contained in Boeing Interim Technical Report D194-10089-1 (Reference 12).

5.1 IDENTIFICATION OF DATA SOURCES

The identification of data sources and the types of data each source was responsible for, or was the historical repository of, covered three primary areas; a) Air Force Agencies, b) Operating Wings, and c) EAC Historical Data Files. Table 11, "Data Sources and Agencies" lists the major command, center or base; geographical location; specific office or wing where data was obtained; and the general type of available data. The various categories of information and detail data elements (parameters, aircraft, bases, and equipments) were established in the preceding tasks.

5.2 DATA ACQUISITION

Once the various sources and their respective types of data had been established the next logical step was to obtain data that was not currently in the EAC Historical Data Bank or to obtain an update of more current information. Since this study was initiated in early 1978,

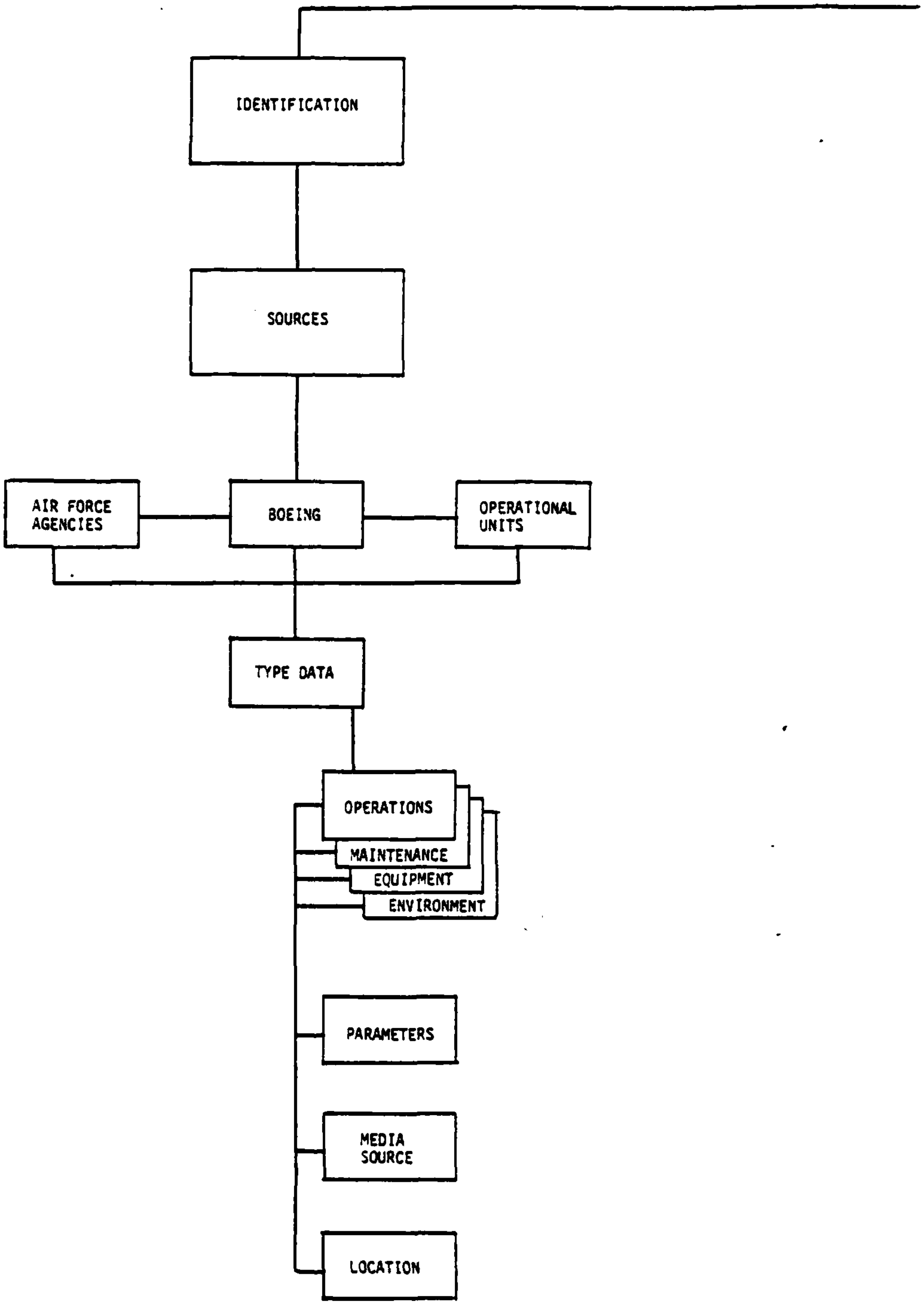


FIGURE 8 - IDENTIFICATION AND INTEGRATION OF DATA SOURCES - TASK IV - FLOW DIAGRAM

Sheet 1 of 3

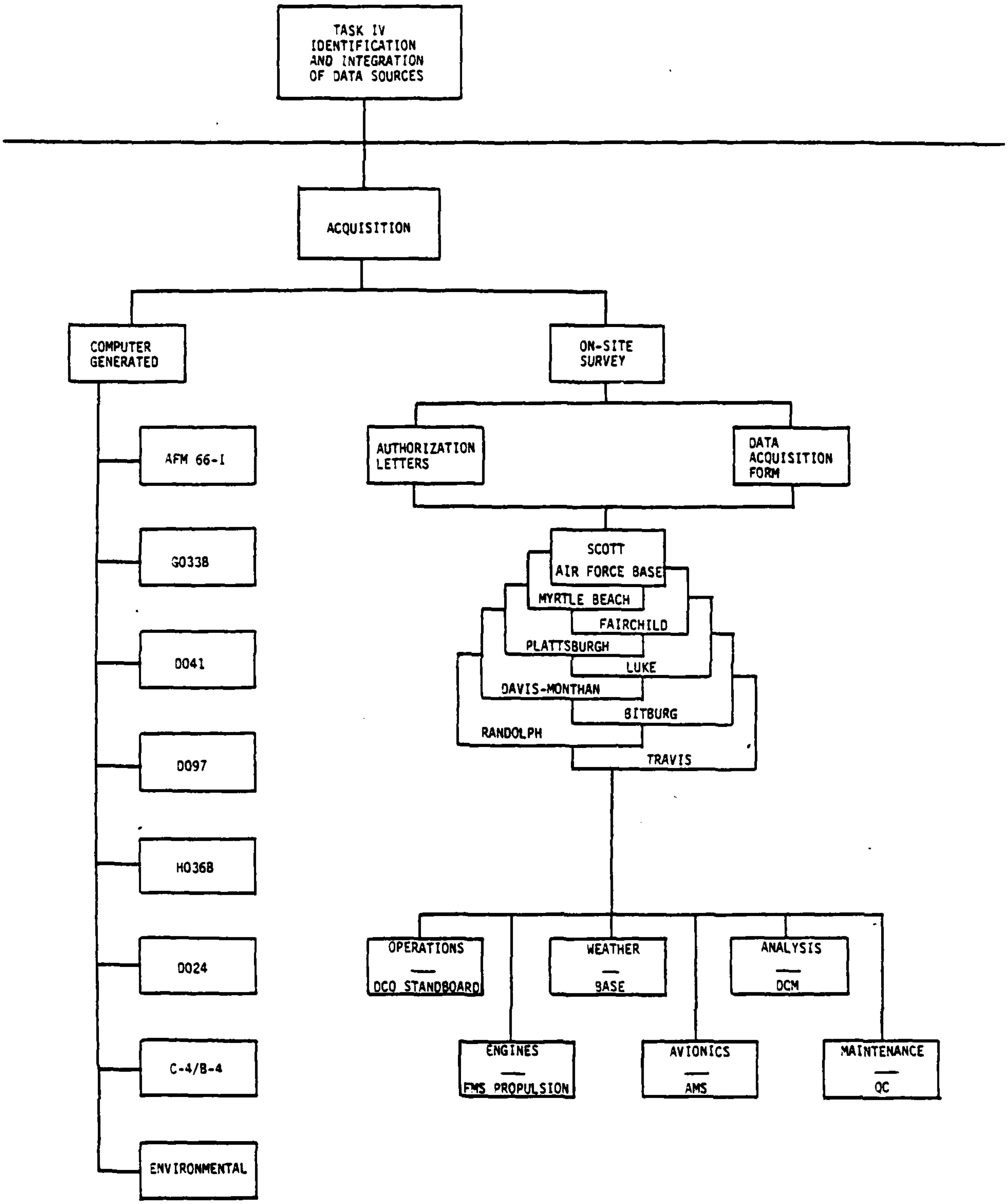


FIGURE 8 - IDENTIFICATION AND INTEGRATION OF DATA SOURCES - TASK IV - FLOW DIAGRAM (Cont'd)

Sheet 2 of 3

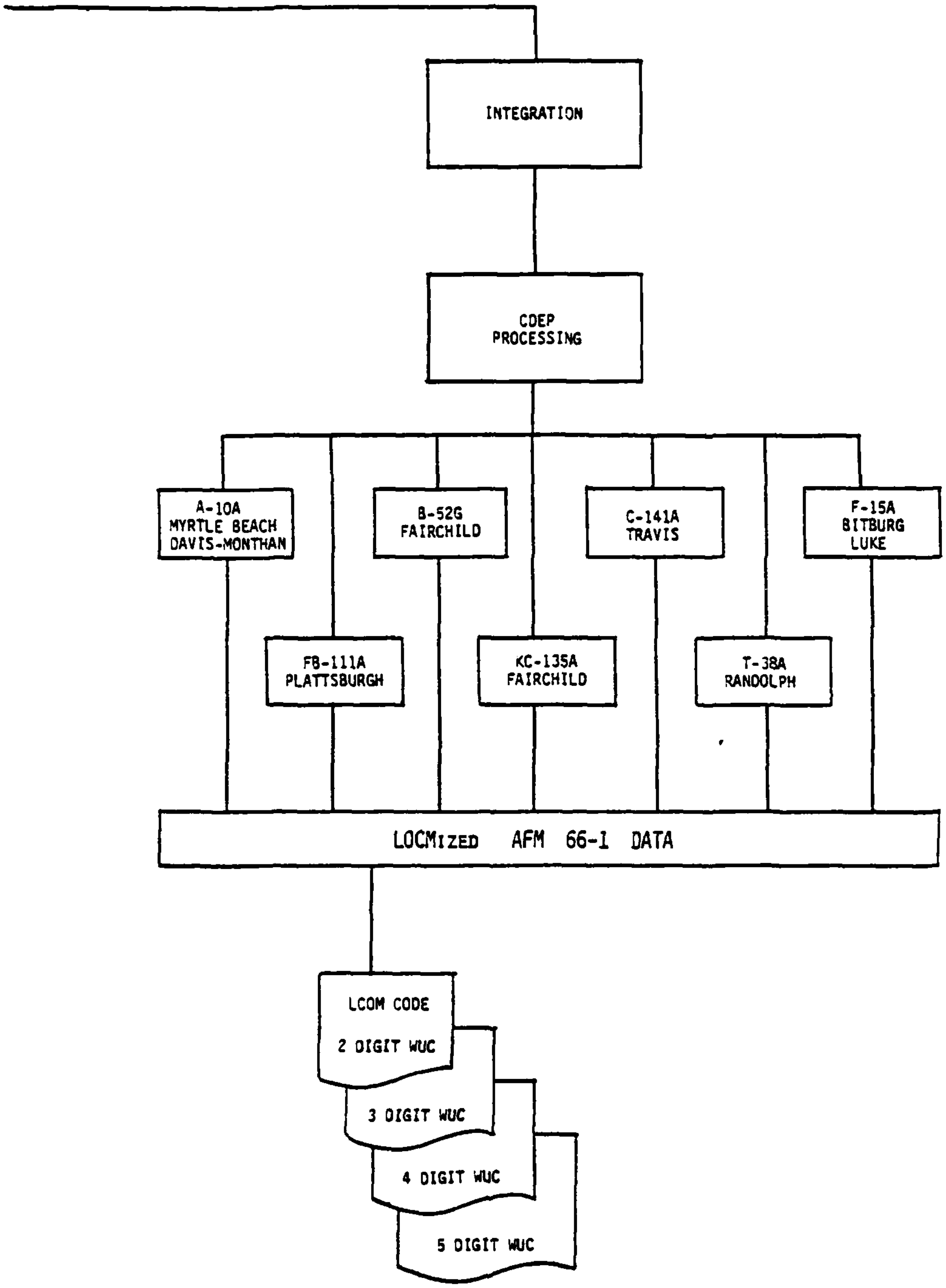


FIGURE 8 - IDENTIFICATION AND INTEGRATION OF DATA SOURCES - TASK IV - FLOW DIAGRAM (Cont'd)

Sheet 3 of 3

TABLE 11 DATA SOURCES AND AGENCIES

AGENCY BASE	LOCATION	OFFICE SYMBOL/FUNCTION OR WING	TYPE OF DATA
Air Force Logistics Command	Wright-Patterson AFB Ohio	ACVMP - Inventory, Status and Performance Branch	D056E G033B C-4, B-4 D097
		LORRA - Analysis Branch DCS/ Logistics Operations	D041
		ACFCS - Comptroller	H036B
Air Force Maintenance and Supply Management Engineering Team	Wright-Patterson AFB Ohio	AFMSMET/(MENT) - Management Engineering Team	LCOM Users Guide LCOM Data Extraction Program Users Document
Air Weather Service (MAC) Environmental Technical Applications Center (ETAC)	Scott AFB, Ill.	ETAC/DO - Director Operations	Weather Parameters Climatic Briefs Monthly Summaries Base Tab "A's"
Myrtle Beach AFB	Myrtle Beach, S.C.	354th TFW	A-10A Statistics
Fairchild AFB	Spokane, Wash.	92nd BMW	B-52G/KC-135A Statistics
Plattsburgh AFB	Plattsburgh, N.Y.	380th BMW	FB-111A Statistics
Luke AFB	Glendale, Ariz.	58th TTW	F-15A Statistics
Davis-Monthan AFB	Tucson, Ariz.	355th TFW	A-10A Statistics
Bitburg AB	Bitburg, Germany	36th TFW	F-15A Statistics
Travis AFB	Fairfield, Calif.	60th MAW	C-141A Statistics
Boeing Aerospace Company	Seattle, Wash.	Experience Analysis Center (EAC)	Aircraft Historical Data Processed AFM 66-1 Maintenance Data Operational Data Technical Descriptive Information
Air Force Inspection and Safety Center (AFISC)	Norton AFB, Calif.	AFISC/SER	Aircraft Mishap Data (Accident/Incident)

the most recent data that would be available from the various repositories was 1977. Therefore, since 1977 was a typical year in peacetime Air Force operations, it was chosen as the base period for study data base development. Many of the parameters used in the study fluctuate with time. However, when averaged over a typical year's operation, value drift is not great. Over many years operations values can vary significantly as is dramatically portrayed in Reference (1) on the C-130E aircraft since many of the same data elements are common. Therefore, follow-on research in this study area would do well to consider the effect of averaging several year's data.

In obtaining the specific data types, the task logically divided into computer generated type information and data that must be obtained from an on-site survey.

5.2.1 COMPUTER GENERATED DATA

Although all the data obtained in this study was eventually computer manipulated, in one form or another, the following discussion pertains only to that data received on magnetic tape.

5.2.1.1 AFM 66-1 (D056E) - Maintenance Management Data

For the seven study aircraft all AFM 66-1 data had been previously processed for 1977 except the T-38A. This had to be ordered through the Air Force Systems Command (AFSC) via AFLCR/AFSCR 178-6 and processed. A total of over five million records or maintenance transactions were either previously available or obtained on the subject aircraft.

5.2.1.2 G033B - Standard Aerospace Vehicle Inventory, Status and Utilization Reporting System

This system provided the operational parameters necessary for various rates, such as maintenance manhours per flight hour, utilization, etc. as well as the operational ready and not operational ready rates per specific categories.

5.2.1.3 D041 - Recoverable Consumption Item Requirements System

D097 - Interchangeability and Substitution Data Maintenance System

H036B - DMIF Cost Accounting/Production Report

These three data systems comprised the depot data used in various trades made during equipment selection and verification. The two million plus records contained such significant parameters as equipment cost, maintenance flow time through base and depot, and maintenance manhour expenditures.

(1) "Life Cycle Cost of C-130E Weapon System," Ibid.

5.2.1.4 B-4/C-4 - Reference Data Tapes

These tapes, although not supplying any investigative parameters per se, are critical in tracking a given aircraft component from AFM 66-1 to depot data. They contain cross references to part number, work unit code, and national stock number.

5.2.1.5 Environmental

This information, obtained from ETAC, represents the computerized weather information for each of the eight bases visited. These included such parameters as snow fall, rain days, humidity, etc.

5.2.2 ON-SITE SURVEY BY BASE VISITS

As in any data acquisition task of this magnitude, all the necessary parameters have not been computerized. This necessitates on-site visits to obtain the data. Not only does it fill in the missing parameters but it serves to validate the processed data. An equally important function is the establishment of data parameter specialists or points of contact that can be consulted with during the detail analysis of the data.

5.2.2.1 AUTHORIZATION LETTER

To visit any operational unit, authorization was required from the respective command. Appendix B shows a typical letter used that included the following pertinent items:

a) Contract Number and Name
b) Introduction
c) Objective
d) Assistance required and point of contact
e) Authorizing signatures

It is imperative that these be forwarded well in advance of the intended time of visit to allow for any contingencies that may occur at the base. Not only did this procedure work satisfactorily throughout the entire study but the points of contact were contacted immediately, once known, and again a week prior to the visit. This personal contact eliminated any last minute problems and established an excellent rapport with the base personnel.

5.2.2.2 DATA ACQUISITION FORM

Prior to traveling to any base, a series of forms (see example in Appendix C) were developed listing the specific data parameters or narrative information desired by function, i.e., avionics, engines, fuel, hydraulics, etc. These forms proved to be invaluable in that they provided a consistent, systematic approach at each base. These were distributed to the respective technicians, where practical, and proved to be the most economical and expeditious method to gather all the data.

5.2.2.3 BASE VISITS

At each base depicted in Figure 9, it was necessary to visit six major areas. The first and most significant was the DCM Office. Here a short introductory presentation was given to all functional OIC's/NCOIC's from which data was required. This one time meeting set the stage for a smooth transition of data flow with all concerned namely:

a) Operations - The DCO or standardization pilot covered the aircraft characteristics.

b) Weather - Base weather provided obstructions to vision by month.

c) Analysis - Monthly maintenance summaries and support general data via a BLIS printout.

d) Quality Control (QC) - QC answered general type questions on aircraft maintenance.

e) Avionics Maintenance Squadron (AMS) - AMS provided the data for all avionics equipments.

f) Field Maintenance Squadron (FMS) and Organizational Maintenance Squadron (OMS) - FMS and OMS provided the data for engines and all other non-avionics equipments.

5.3 DATA INTEGRATION

This third and final step of Task IV was primarily a continuation of data preparation for analysis in the ensuing tasks. The AFM 66-1 maintenance expenditure records (D056E) had to be screened and integrated into an LCOM acceptable format.

To accomplish this screening, computer programs were written to manipulate the data per the Common Data Extraction Program (CDEP) User Documentation (Reference 13) specification. This criteria was followed, without deviation, since it would provide the same data as is currently being used by LCOM analysts.

Although these Boeing developed LCOM data programs used CDEP criteria, the output format was unique to the requirements of this study. Each 'LCOM Action Code' (Reference 13), was displayed by study aircraft with the following data elements.

13 "Common Data Extraction Program (CDEP)" AFMSMET, March 1978.

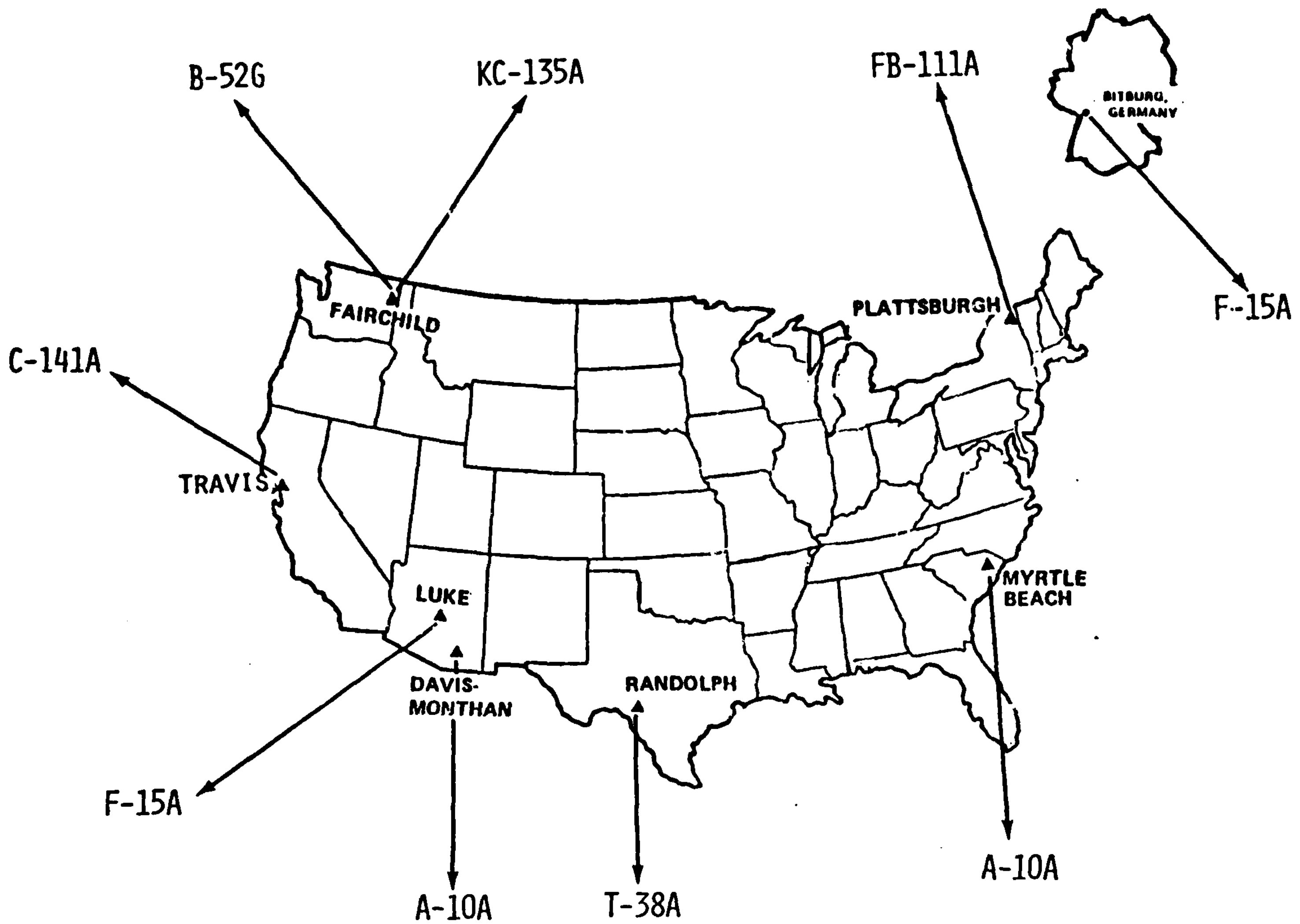


FIGURE 9 BASES VISITED

a) WUC at all indentures (2, 3, 4, 5).
b) Units produced count
c) JCN count (summation of different JCN's)
d) Manhours
e) Clockhours

Table 12 is a graphical display of these indentured LCOM type actions for the F-15A at Luke AFB.

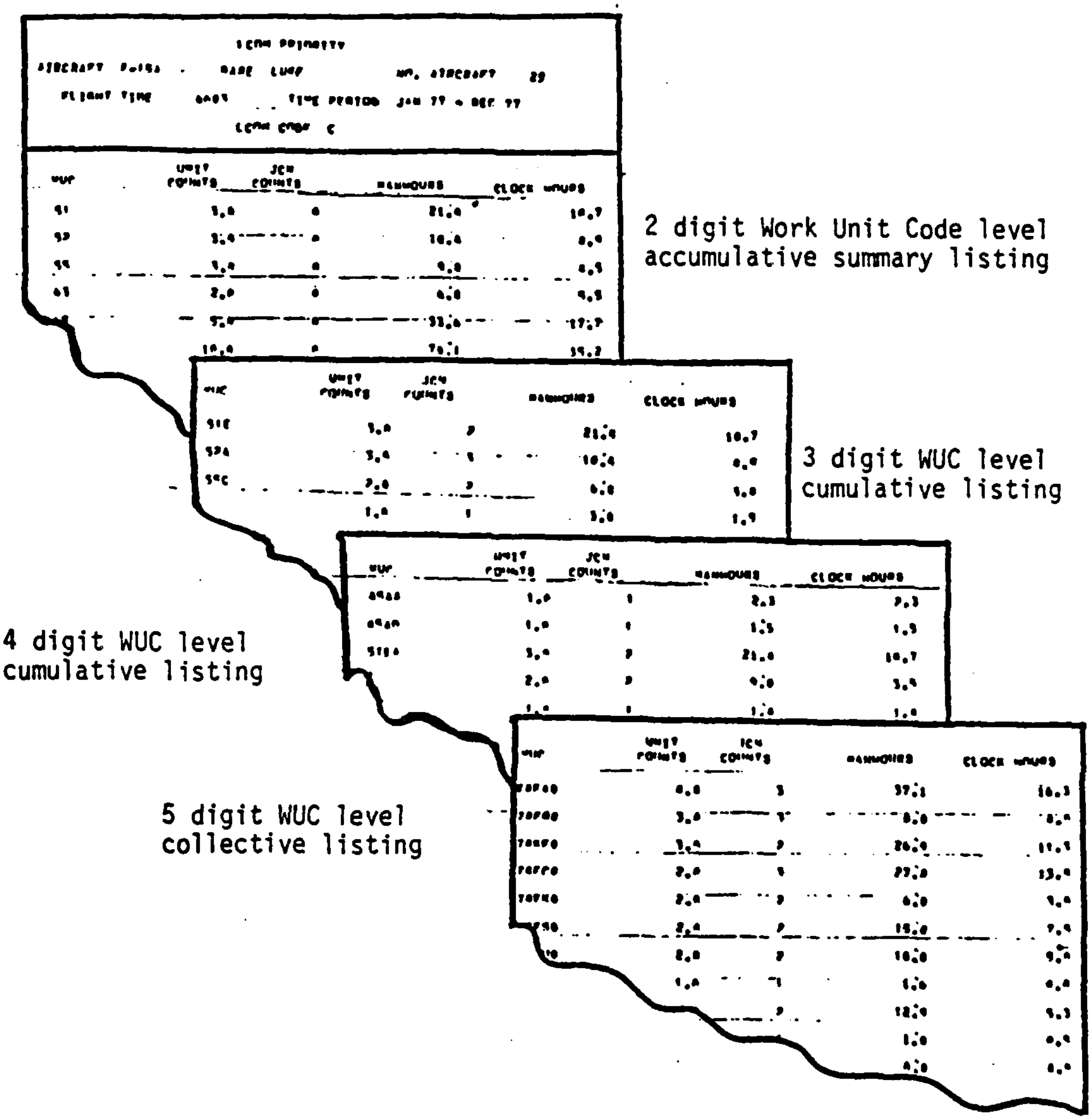
The complete procedures developed consisting of 30 subsystems and seven sort modules are described in detail along with flow charts in Boeing Document BCS-G1109, "CDEP Production System) (Reference 14).

This processing of AFM 66-1 data for the seven different aircraft types commenced with approximately seven million records. Selecting only the data for the study aircraft at the bases visited reduced the count to approximately 1.4 million records. Also, the flight time and number of aircraft in the data sample was reduced from 826,823 flight hours and 1,695 aircraft to 135,835 and 362 respectively.

Completion of this data processing for each aircraft at each base and the supplemental data obtained from the acquisition phase (letters and on-site visits) provided a substantial data base of varied parameters for the follow-on analysis tasks.

14 Boeing Document BCS "CDEP Production System," February 1979.

TABLE 12 LCOMIZED AFM 66-1 DATA FORMATS



6.0 ANALYZING AND PRIORITIZING PARAMETERS - TASK V

Task V of the study was to perform an analysis of the field experience data base accumulated by the first four study tasks. The objective of the analysis was the detection, testing and ranking of possible statistically useful causal relationships between the candidate maintenance impact parameters (See Tables 4 through 10, section 4) and maintenance resource demand variables (See Table 3, section 4) selected in Task III. If new strong relationships were detected for each equipment type studied, then these basic two variable parametrics could be used to build composite maintenance demand models (Maintenance Metrics) during the course of Tasks VI and VII.

The general Task V approach divided the analysis into subtasks as shown in Figure 10. The preparation and execution of these subtasks are discussed in the following paragraphs. This approach is deliberately intended as a generalized step-by-step outline of the methodology involved so that other studies can duplicate and/or expand the research using widely available computerized statistical packages such as "SPSS" (Reference 19), and "STATPK" (Reference 16). The analysis as performed by Boeing Experience Analysis Center utilized a Boeing developed computer program, "PKING," which automatically combined several subtasks in order to facilitate and speed up the parametric relationship detection and testing process. Utilizing this local program allowed 24,460 variable combinations to be tested within the allotted effort.

The Task V procedure was applied to the quantification and normalization of the source data accumulated during the first four tasks, and the tabulation of this data into a Master Input Data File suitable for computer input and processing. Processing the data with the "PKING" crossplotting and regression analysis program resulted in the generation of almost 27,000 scattergrams of the eight selected Maintenance Resource Demand (MRD) parameters as functions of the various candidate Maintenance Impact Parameters in the categories of MRD, Equipment, Operations, Environmental, Maintenance, and Aircraft General (refer to Section 4.0 Tables 3 through 10 for parameter list). These scattergrams were screened according to the criteria of (1) 0.5 or better correlation coefficient of regression; or -- (2) Visually apparent curvilinear relationships; with -- (3) Acceptable data point distribution; and -- (4) At least 5 data points, 4 of which are non-zero in both ordinate and abscissa. The screening process resulted in the rejection of 89% of the trial relationships tested. The remaining 11% (2900 scattergrams) were collated in a Maintenance Impact Estimating Relationship (MIER) catalog and published as a supplement to Boeing report,

19 "SPSS Statistical Package for the Social Sciences," Norman Nie, Dale H. Bent, C. Hadlai Hall; McGraw-Hill Book Company, Inc., 1970.

16 BCS-10201-019-R1 "MAINSTREAM-CTS Interactive Statistics Package (STATPK)," Boeing Computer Services, Seattle, Washington, March 1978.

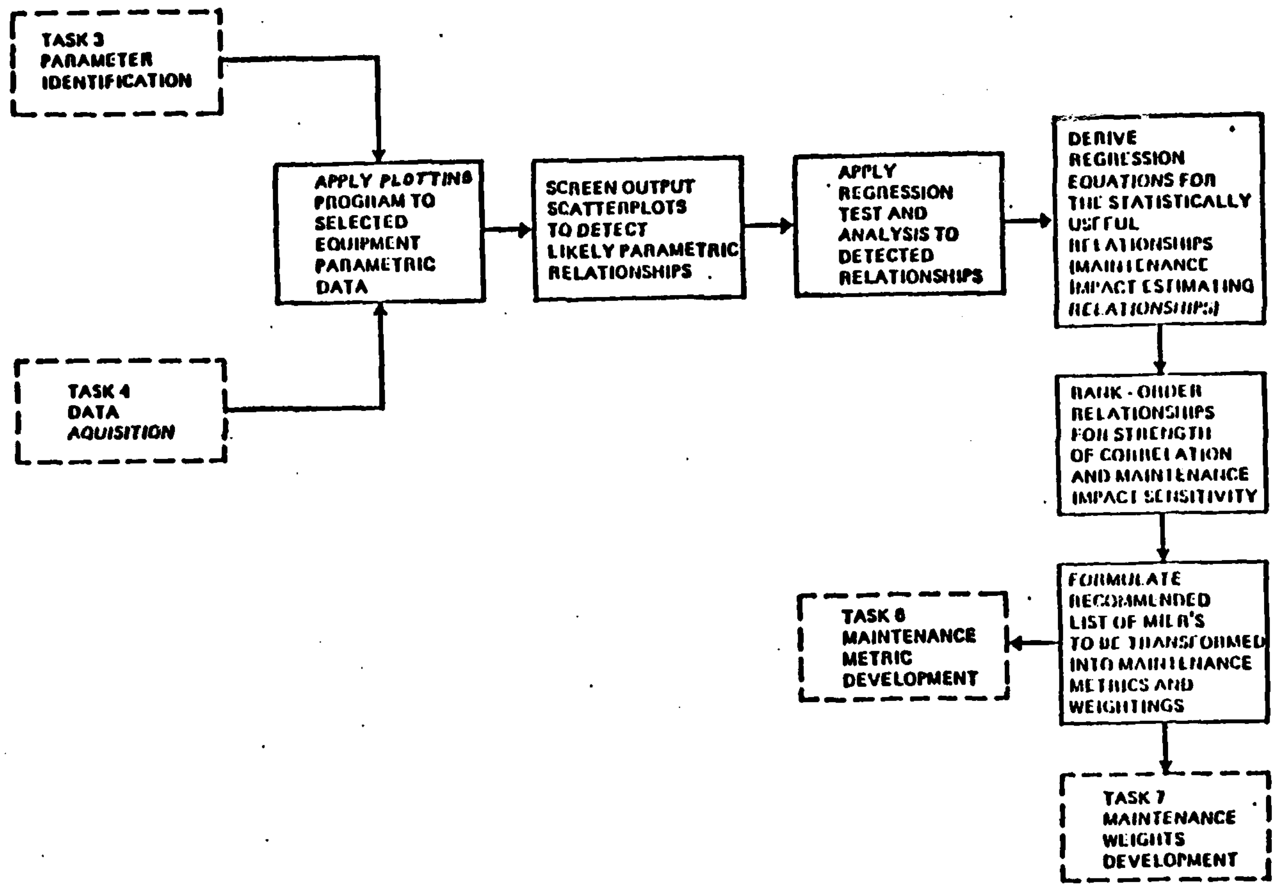


FIGURE 10 TASK V PROCESS FLOW

D194-10089-2 (Reference 15). Eight hundred forty eight (848) of these relationships involved the MRD parameter "Maintenance Action Demand" as a function of various Maintenance Impact Parameters. These significant relationships were used as source data for the development of the maintenance metrics models during Tasks VI and VII. The remaining MIERs composed of the other MRD functions have been cataloged in the above-mentioned supplement and are available for future studies and related research. Complete details and data pertaining to Task V study efforts are contained in Reference 15.

6.1 INPUT DATA PREPARATION

Before maintenance resource demand/maintenance impact parameter variable combination testing and screening could proceed, the packages of data and information gathered in Task IV were classified, quantified and/or normalized where necessary, and tabulated in numerical data sets suitable for computer-aided cross-plotting and simple regression analysis. Figure 11 depicts the preliminary input data processing. Dummy variables were created and scaled where necessary to quantify qualitative data. Quantitative data were normalized or averaged where necessary. Independent and dependent trial regression variables were selected. As shown in Figure 11, the individual data packages for the items in each functional equipment group (subsystem) selected in Task II were integrated into a composite data package for each group. Subsystem equipment groups were functionally normalized across all sample aircraft from Task II and the parameter value data for each equipment item integrated into subsystem group values through a weighted average process. These composite data were next entered in the Master Input Data records. This master file was then transformed to proper computer input format and entered in the "Keypunch Master File" prior to creation of punch-card, magnetic tape, or magnetic disk data input files suitable for computer processing. The format Keypunch Master File created for Task V was tailored for the PKING data processing program. The general process for creating the Master Input File is widely applicable, however, and could be used to create input files for a wide variety of data processing programs. The detailed procedure used in quantifying and integrating the "raw" data base accumulated during Task IV is as follows:

15 Boeing Interim Technical Report "Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems (Parameter Prioritization)" D194-10089-2, October 1979.

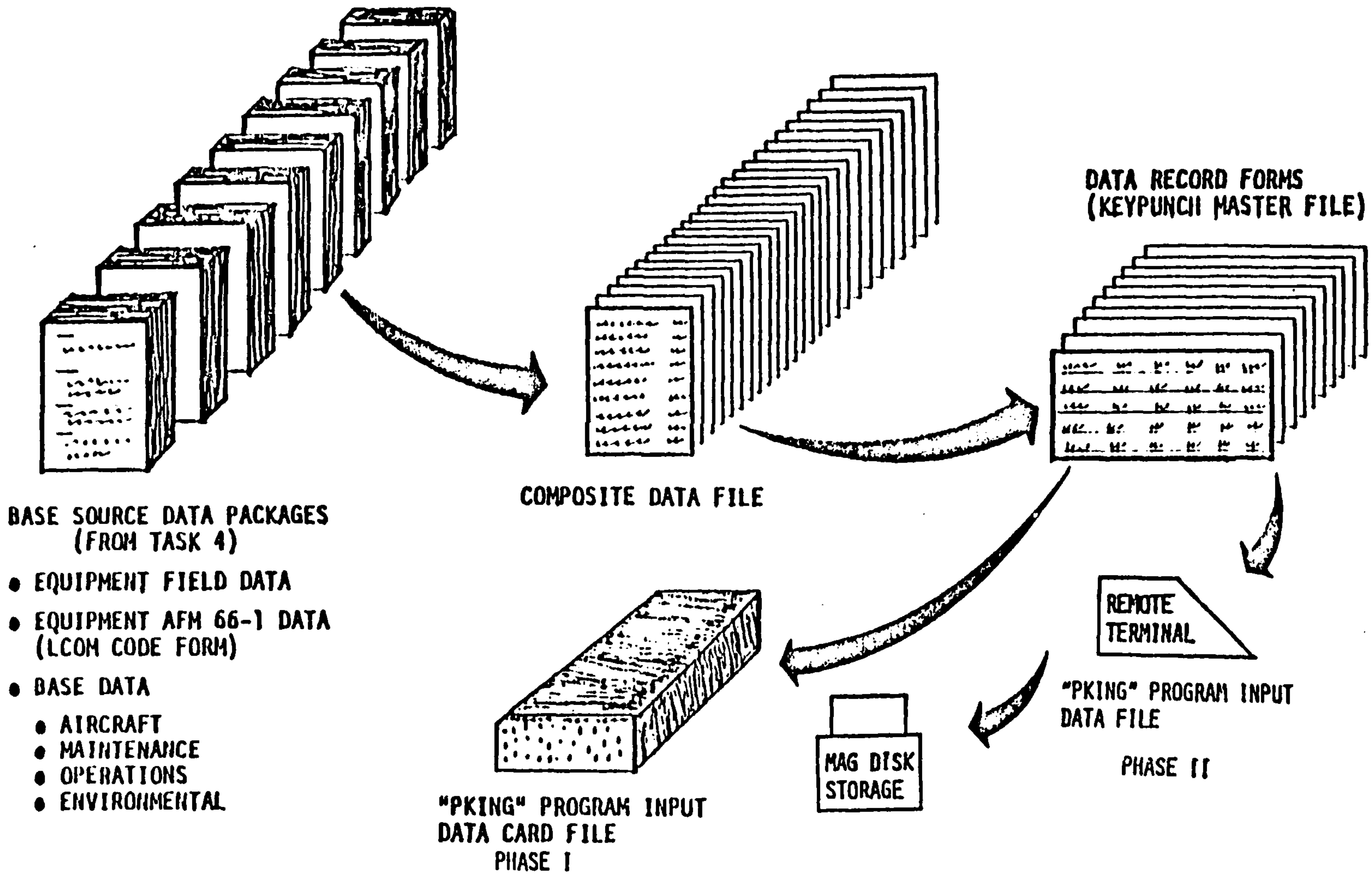


FIGURE 11 TASK V PRELIMINARY INPUT DATA PROCESSING

6.1.1 MASTER INPUT FILE CREATION

The field experience data gathered during Task IV was divided into six categories:

(1) Maintenance Resource Demand Parameters
(2) Equipment Characteristics Parameters
(3) Base Operations Characteristics Parameters
(4) Base Environment Characteristics Parameters
(5) Base Maintenance Characteristics Parameters
(6) General Aircraft Characteristics Parameters

Information on each parameter in the first two categories was obtained for each equipment item selected from each study aircraft at each study base. Information was obtained on an aircraft/base basis for the other four categories. This information was normalized on a subsystem basis as appropriate and entered into composite data files. Since the data in categories (1) and (2) were gathered on each individual equipment item within each functional grouping (subsystem), data on these individual equipment items required transformation into subsystem level values. This was accomplished by a simple weighted average method based on the relative frequency of maintenance of the equipment items comprising a particular subsystem within a particular study aircraft type. For instance, if item A and item B comprise functional subsystem C for a particular aircraft, and the Maintenance Action Demand for item A is twice that of item B (say 10 actions per unit per year vs 5 actions/unit/year), then equipment characteristic parameter values for item A would be weighted twice as heavily as B values when calculating the composite value of subsystem C. For example, if A's volume is 4 cubic inches and B's volume is 7 cubic inches, the weighted average volume of subsystem C for maintenance resource demand purposes is -- $(4+4+7) \div 3 = 5$ cubic inches. This is the value entered in the composite data file and represents the average volume of items removed from subsystem C that must be dealt with by the maintenance system over the course of a year's activity. This same type of reasoning was applied to the calculation of the composite values of the other equipment characteristic parameters.

Most of the data in the data base was obtained in quantitative form. Information on a few parameters was obtained in qualitative form, however, and required quantification. Table 13 shows an example list (equipment characteristics parameters - propulsion) of the identification developed for each of the parameter input data categories. Table 13 shows the category of parameters, their type (real or scaled variable), their units of measure if any, and the scaling conventions used for variables which were scaled from qualitative data.

TABLE 13 EQUIPMENT CHARACTERISTICS PARAMETERS (PROPULSION) - EXAMPLE

PARAMETER NAME	TYPE	UNITS
Total No. of Installed Engines	Real	Number/Acft.
Take-off Thrust Per Engine	Real	Pounds/10
Weight Per Engine	Real	Pounds/10
Volume Per Engine	Real	Cu. Ft./10
Density Per Engine	Real	Lb/Cu.Ft./10
No. Compressor Sections Per Engine	Real	Number
No. Compressor Blades Per Engine	Real	Number
Turbine Section Size	Real	Ft. Diam
Max Engine Combustion Temp.	Real	Degrees "C"
Max Engine Fuel Flow	Real	Lbs/Hr
Min Engine Fuel Flow	Real	Lbs/Hr
Engine Prime Depot	Scaled	Convention: 1 = OCALC 2 = SAALC 3 = Teledyne 4 = Alameda
Engine AGE Availability	Real	% Time Available When Required
Engine AGE Unreliability	Real	% Time Unreliable When Used
Engine Vibration Factors	Real	Convention: 1 = Low 2 = Medium 3 = High

6.2 COMPUTER-AIDED DETECTION AND SCREENING OF PARAMETRIC RELATIONSHIPS

After the Master Input Data File was transformed into suitable computer input records, the Boeing Experience Analysis Center's local cross-plotting and regression analysis program "PKING" was applied to the data. This program was set to generate cross-plots and regression statistics for the following candidate variable combinations:

8 Maintenance Resource Demand Parameters (Avionics subsystems)
8 Maintenance Resource Demand Parameters (Propulsion system)
6 Maintenance Resource Demand Parameters (Other subsystems)
18 Avionics Equipment Parameters (Avionics subsystem)
15 Propulsion Equipment Parameters (Propulsion system)
24 Other Equipment Parameters (Other subsystems)
33 Operations Parameters
30 Environmental Parameters
29 Maintenance Parameters
15 General Aircraft Parameters

A set of cross-plots and regression statistics was generated for each of the 30 following equipment subsystem types:

Phase I

- Propulsion
- Flight Indicators
- Air Data System
- Horizontal Situation Indicator
- Autopilot
- UHF Communication Set
- IFF Transponder Set
- Inertial Navigation Set
- Instrument Landing Set
- TACAN Set
- Attitude Heading Ref. Set
- Radar Set

Phase II

- Radomes
- Windshields
- Wings
- Cockpit Furnishings
- Landing Gear
- Brakes
- Stabilator
- Rudder
- Flaps
- Environmental Control System
- Electrical Power
- Navigation Lights
- Landing/Taxi Lights
- Hydraulic Power
- Internal Fuel
- Oxygen
- LOX
- Fire Detection

The data cases used as the statistical base for the analysis of these equipments was gathered for the following aircraft/base combinations during the course of Task IV:

- F-15A/Luke AFB, Arizona
- F-15A/Bitburg AB, Germany
- B-52G/Fairchild AFB, Washington
- FB-111A/Plattsburgh AFB, New York
- C-141A/Travis AFB, California
- KC-135A/Fairchild AFB, Washington
- T-38A/Randolph AFB, Texas
- A-10A/Myrtle Beach AFB, South Carolina
- A-10A/Davis-Monthan AFB, Arizona

Using this nine case data population and the applicable candidate variable combinations, against each of the 30 subsystem equipment types, 26,460 individual scatterplots were generated.

These resulting scatterplots were screened for significant causal relationships between the Maintenance Resource Demand (MRD) parameters and the Candidate Maintenance Impact parameters. The screening criteria utilized were as follows:

(1) Correlation Coefficient of Regression 0.5 or greater.

(2) Visually apparent curvilinear relationship.

(3) Acceptable data point distribution.

(4) At least 5 data points, 4 of which were non-zero in both the ordinate and abscissa.

Of the 26,460 scattergrams generated, the screening process rejected about 8990 as being insufficiently correlated. This left 11% or over 2900 correlated relationships from which to formulate a recommended list of significant Maintenance Impact Estimating Relationships (MIERs).

As stated in the introduction, the same variable combination data processing and screening could have been accomplished with any available computer program possessing cross-plotting and regression analysis capability, for example, SPSS or STATPK (References 19 and 16). Boeing EAC's "PKING" program was used to gain maximum speed and efficiency in processing the mass of data contained in the data base. A brief description of this program follows:

19 "SPSS Statistical Package for the Social Sciences," Ibid.

16 BCS-10201-019-R1 "MAINSTREAM-CTS Interactive Statistics Package (STATPK)," Ibid.

6.2.1 DESCRIPTION AND USE OF "PKING"

The "PKING" program is a data manipulation program written in FORTRAN IV, which can handle moderately large data sets (35 variables, 100 data points per variable) such as are encountered in cost and support system analysis. Program input is flexible and straightforward in the form of data tables. Output is in the form of easy-to-read cross-plots derived from the input variables.

The significant characteristics of the program are as follows:

- The Program records and manipulates data for from 2 to 35 variables.
- As many as 100 entries can be made for each variable.
- All 35 variables may be input variables or --
- A minimum of 2 variables may be input variables.
- Up to 33 of the output variables may be "transform variables" created by transforms within the program.
- Up to 50 transform algorithms may be included in the program to manipulate data and create new output variables --
- A total of 35 output variables (input variables + transform variables) may be specified.
- The transforms may be any "mathematical" or "logical" algorithms.
- A simple least squares regression routine is computed for each variable combination.
- The output of the program consists of scattergrams which plot specific combinations of input and transform variables.
- The plots may be constrained somewhat by specifying that certain input variables only be used as "independent" variables.
- Otherwise all variables are treated in turn as independent variables and dependent variables against all other variables.
- The form of the output scattergrams has been carefully designed to permit rapid visual scanning for two-variable correlations. In addition the appropriate correlation coefficient of regression, and the estimating equation slope and intercept are annotated to each scatterplot.
- Input data and transform data is stored in a single 35-by-100 cell addressable matrix to facilitate inter-program processing and easy linking with other data manipulation programs such as data ranking routines.

6.3 MAINTENANCE IMPACT ESTIMATING RELATIONSHIP (MIER) DEVELOPMENT AND PRIORITIZATION

The next step in the analysis and prioritization of the study parameters was to re-examine the apparently correlated relationships found during the computer processing and screening process and build a "MIER Catalog" of potentially useful relationships. The 2900 odd scattergrams accepted during the first screening were re-examined for reasonable data distribution and statistical usefulness. Several hundred scattergrams which had passed the first screening were rejected during this test because of unacceptable data distribution. For instance, if all data points except one were clustered in one area of the plot, the regression computation often yielded a correlation coefficient greater than 0.5 even though the data were useless for practical purposes. Other scattergrams were rejected on the basis of not enough (4 or more) non-zero data points to have any statistical usefulness. This question of statistical usefulness can be illustrated by referral to Figure 12. Note that at a sample size of 5 (considered the lower useful limit for this study), it can be said with 90% confidence that only about 66% of the possible values of a "total" continuous-valued population lie within the distribution of values represented by the available sample. Conversely, we can only be about 40% confident that 90% of the possible values have been captured by a sample of 5. This condition improves somewhat at the "normal" sample size for this study which consists of 9 data points. At a sample of 9, we can estimate with 90% confidence the capture of nearly 80% of the possible population values, or estimate with 60% confidence the capture of 90% of the possible population values. The nomograph of Figure 12 thus gives a measure of the statistical confidence that can be placed on the relationships derived from the data base of this study.

The surviving MIERs from this second screening process were then sorted first by equipment item and then by MRD type within equipment items. The MIERs within each MRD type within each equipment item were then rank-ordered by correlation coefficient and and collated in a MIER catalog which has been published as a Supplement 1 to Boeing Interim Technical Report D194-10089-2 (Reference 15). Table 14 (sheets 1 through 6) contains a list of study parameters which were found to have significant impact on the maintenance resource demands of the study subsystems. Table 15 (sheets 1 through 9) indicates the specific parameters which impact each MRD for each equipment item. The Maintenance Action Demand MIERs were used to develop new metrics for LCOM (Tasks VI and VII) while those in the other maintenance resource demand categories are retained for future study. Figure 13 illustrates typical examples of the MIER relationships that were cataloged, and Figure 14 shows the total MIERs detected and retailed.

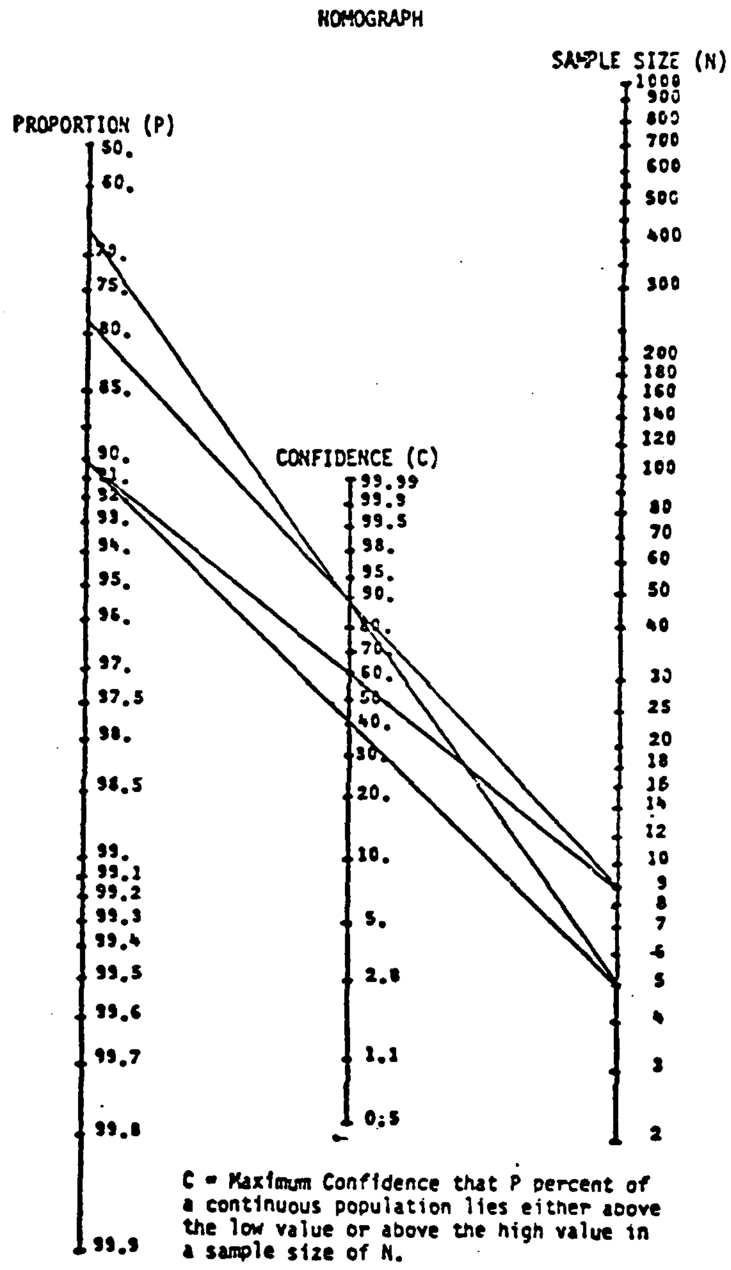


FIGURE 12 NON PARAMETRIC TOLERANCE LIMITS (SINGLE TAIL OR ONE SIDED TEST)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS

Variable I.D. Number	Label Name
	ENGINE PARAMETERS
P02	Total Number of Installed Engines
P03	Take-Off Thrust per Engine
P04	Weight per Engine
P05	Volume per Engine
P13	Engine Prime Depot
P15	Engine Age Unreliability
P17	Total Maintenance Manhours per Installed Engine
P18	Total Engine Maintenance Manhours per Aircraft
P19	Total Engine Removals per Aircraft
P20	Unscheduled Engine Removals per Aircraft
P23	Engine Air Aborts per Aircraft
	AVIONICS PARAMETERS
A02	Equipment Location on Aircraft
A03	Equipment Weight
A04	Equipment Volume
A05	SRU Count
A06	Operating Temperature
A07	Cooling Method
A08	Protective Devices
A09	Number of Test Points (Org. Level)
A10	Required Age
A11	Age Availability
A12	Age Unreliability
A13	Average Operating Time per Sortie
A14	Failure/Malfunction Causes
A15	Retest OK Rate
A16	On-Off Cycles per Flying Hour
A18	Ground/Flight Operating Ratio
A19	Failure/Abort Ratio
A21	Equipment Total Maintenance Manhour per Aircraft
A22	Equipment Total Removals per Aircraft
A23	Equipment Unscheduled Removals per Aircraft
A26	Equipment Air Aborts per Aircraft
A27	Equipment Cannibilizations per Aircraft

(SHEET 1)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS

Variable I.D. Number	Label Name
	OTHER EQUIPMENT PARAMETERS
F01	Location of Equipment on the Aircraft
F02	Primary Material - Composition Technology Level
F03	Equipment Weight
F04	Equipment Volume
F05	Operating Temperature
F06	Support Equipment Complexity
F07	Support Equipment Reliability
F08	Type of Failure Problems
F09	Inflight Squawk Verification Rate
F10	On/Off Cycles per Sortie
F11	Ground to Flight Operating Ratio
F13	Removals to Access Other Equipment
F15	Principle Failure Cause
F16	Equipment Protection Methodology
F17	Equipment Pressurization Level
F22	Landings per Tire (Tires)
F24	Securing Method Technology
	MAINTENANCE RESOURCE DEMAND (MRD) PARAMETERS
R02	Equipment Total Maintenance Manhour per Aircraft
R03	Equipment Total Unscheduled Removals per Aircraft
R04	Equipment Ground Aborts per Aircraft
R05	Equipment Air Aborts per Aircraft
R06	Equipment Cannibilizations per Aircraft

(SHEET 2)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS

OPERATIONAL PARAMETERS

Variable I.D. Number	Label Name
002	Years Aircraft Have Been on Base
003	Average Mission Mix
005	Average Take-Off Speed
006	Median Take-Off Distance
007	Percent of Maximum Take-Off Weight
008	Average Climb Rate
009	Average Cruise Speed
010	Average Cruise Altitude
011	Average Descent Rate
012	Average Landing Speed
013	Minimum Landing Distance
014	Average Landing Weight
015	Total Flying Hours per Aircraft
016	Training Flying Hours per Aircraft
017	Operations Flying Hours per Aircraft
018	Misc. Flying Hours per Aircraft
019	Total Landings per Aircraft
020	Training Landings per Aircraft
021	Operations Landings per Aircraft
022	Misc. Landings per Aircraft
023	Average Number of Aircraft on Alert
024	Average Number of Deployed Aircraft
025	Total Sorties per Aircraft
026	Training Sorties per Aircraft
027	Operations Sorties per Aircraft
028	Misc. Sorties per Aircraft
029	Average Possessed Aircraft
030	Maximum Aircraft Speed
031	Maximum Aircraft Ceiling
032	Aircraft Crew Size
033	Average Sortie Length
034	Accidents (Major/Minor) per Aircraft
035	Incidents per Aircraft

(SHEET 3)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS
ENVIRONMENTAL PARAMETERS

Variable I.D. Number	Label Name
E02	Base Altitude
E03	Runway Direction
E04	Distance to Mountains
E05	Direction of Mountains
E06	Number of Snow Days
E07	Total Snow Fall
E08	Mean Snow Depth
E09	Number of Rain Days
E10	Total Rain Fall
E11	Number of Hail Days
E12	Relative Humidity (Average)
E13	Number of Thunder Days
E14	Number of Sleet Days
E15	Number of Fog Days
E16	Predominate Wind Direction
E17	Maximum Crosswind's Less Than 10 MPH
E18	Maximum Crosswind's 10-19 MPH
E19	Maximum Crosswind's 20-29 MPH
E20	Maximum Crosswind's 30-39 MPH
E21	Maximum Crosswind's 40-49 MPH
E22	Maximum Crosswind's Greater Than 50 MPH
E23	Mean Temperature
E24	Mean Minimum Temperature
E25	Mean Maximum Temperature
E26	Days Maximum Temperature was Above 80^{o} "F"
E27	Days Minimum Temperature was Below 32^{o} "F"
E28	Total Number of Obstructions to Vision
E30	Average Obstruction Type
E31	Average Obstruction Severity

(SHEET 4)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS

MAINTENANCE PARAMETERS

Variable I.D. Number	Label Name
M02	Average OR Rate
M03	Average NORM Rate
M04	Average NORS Rate
M05	Total Maintenance Personnel Authorized
M06	Total Maintenance Personnel Assigned
M07	Total 3 Level Maintenance Personnel Assigned
M08	Total 5 Level Maintenance Personnel Assigned
M09	Total 7 Level Maintenance Personnel Assigned
M10	Total 9 Level Maintenance Personnel Assigned
M11	Total Maintenance Personnel Authorized (AMS)
M12	Total Maintenance Personnel Assigned (AMS)
M13	Total 3 Level Maintenance Personnel Assigned (AMS)
M14	Total 5 Level Maintenance Personnel Assigned (AMS)
M15	Total 7 Level Maintenance Personnel Assigned (AMS)
M16	Total 9 Level Maintenance Personnel Assigned (AMS)
M17	Total Maintenance Manhours Expended per Aircraft
M18	AMS Maintenance Manhours Expended per Aircraft
M20	Average Turn-Around Time - Maintenance
M21	Aircraft FOD (All Causes)
M22	Total General Support (01-09) Manhours per Aircraft
M23	Total General Support - 01 Manhours per Aircraft Ground Handling and Servicing
M24	Total General Support - 02 Manhours per Aircraft Aircraft Cleaning
M25	Total General Support - 03 Manhours per Aircraft Look Phase of Scheduled Inspections
M26	Total General Support - 04 Manhours per Aircraft Special Inspections
M27	Total General Support - 05 Manhours per Aircraft Preservation and Storage
M28	Total General Support - 06 Manhours per Aircraft Arming and Disarming
M29	Total General Support - 07 Manhours per Aircraft Preparation and Maintenance of Records
M30	Total General Support - 09 Manours per Aircraft In-Shop General Support

(SHEET 5)

TABLE 14 SIGNIFICANT MAINTENANCE IMPACT PARAMETERS

AIRCRAFT GENERAL PARAMETERS

Variable I.D. Number	Label Name
G02	Years Since Aircraft was Produced
G03	Aircraft Empty Weight
G04	Maximum Gross Weight - Take-Off
G05	Aircraft Wing Area
G06	Aircraft Aspect Ratio
G07	Total Fuel Capacity
G08	Average Aircraft Wing Load
G09	Years Since Engine Production
G10	Number of Installed Engines per Aircraft
G11	Engine Weight per Aircraft (All Engines)
G12	Total Thrust per Aircraft
G13	Designated Climb Rate
G14	Number of Generator's per Aircraft
G15	Total Maintenance Manhour per Flight Hour
G16	Years Since Aircraft First Flight

(SHEET 6)

TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
PROPULSION	MAINTENANCE ACTION DEMAND	P02,P04,P05,P17,P18,P19,P20,Ø08,Ø10,Ø14,Ø27,Ø32,Ø33,E13,E18,E20,M07,M08,M09,M10,M11,M12,M13,M14,M22,M24,M25,M30,G02,G03,G04,G05,G07,G09,G10,G11,G12
	MAINTENANCE MANHOURS EXPENDED	P02,P04,P05,P13,P17,P19,P20,Ø08,Ø10,Ø14,Ø32,Ø33,E03,E13,E18,M07,M08,M09,M10,M11,M12,M13,M14,M17,M23,M24,M25,M30,G02,G03,G04,G05,G07,G09,G10,G11,G12
	TOTAL EQUIPMENT REMOVALS	P04,P05,P13,P15,P20,Ø11,Ø14,Ø25,Ø27,Ø32,M07,M08,M09,M10,M11,M12,M13,M14,M18,M23,M24,M25,G03,G04,G05,G11,G12
	UNSCHEDULED EQUIP. REMOVALS	P04,P05,P13,P17,Ø10,Ø11,Ø14,Ø32,M07,M08,M09,M10,M11,M12,M13,M14,M23,M24,M25,G03,G04,G05,G11,G12
	SCHEDULED EQUIP. REMOVALS	P03,Ø11,Ø25,Ø35,M02,M03,M05,M06,M07,M08,M09,M10,M11,M12,M13,M14,M24,G13
	AIR ABORTS	P04,Ø06,Ø14,Ø19,Ø20,Ø25,Ø26,Ø32,Ø33,Ø35,E23,E26,E27,M20,M21,G03,G04,G05,G06,G07,G09,G10,G11,G12,G15
	GROUND ABORTS	P04,P05,P13,P23,Ø07,Ø08,Ø14,Ø19,Ø20,Ø24,Ø26,Ø29,Ø32,Ø33,E13,E18,E23,E26,M10,M11,M12,M13,M14,M21,M26,G03,G04,G05,G06,G07 G08,G09,G11,G12,G14
	EQUIPMENT CANNIBALIZATION	Ø08,E09,E10,E12,E15,E25,E28,E31,M03
FLIGHT INDICATORS	MAINTENANCE ACTION DEMAND	A03,A06,A10,A15,A21,A22,A27,Ø11,Ø13,Ø15,Ø17,E02,E03,E18,E19,E20,M07,M08,M11,M12,M13,M14,M17,M29,G08
	MAINTENANCE MANHOURS EXPENDED	A03,A04,A06,A09,A10,A15,A19,A22,A27,Ø11,E02,E03,E16,E19,M07,M11,M12,M13,M14,M29,G08
	TOTAL EQUIPMENT REMOVALS	A03,A06,A09,A10,A15,A19,A27,Ø19,E02,E19,M29,G06,G08
	UNSCHEDULED EQUIP. REMOVALS	A03,A06,A09,A10,A15,A19,A27,Ø19,E02,E19
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A03,A09,Ø10,E02,E05,E19,E21,M29,G06,G08
AIR DATA SYSTEM	MAINTENANCE ACTION DEMAND	A03,A07,A10,A16,A18,A19,A21,A23,A26,Ø08,Ø13,Ø14,Ø15,Ø22,Ø23,Ø32,E13,E18,E19,E20,M03,M07,M08,M10,M11,M12,M13,M14,M17,M22,M23,M24,M25,M28,M29,G03,G04,G05,G08,G09,G11,G12
	MAINTENANCE MANHOURS EXPENDED	A03,A04,A07,A10,A23,A26,A27,Ø08,Ø11,Ø23,E13,E16,E18,E19,E20,M03,M07,M08,M10,M11,M12,M13,M14,M17,M22,M23,M24,M27,M29,G08,G12
	TOTAL EQUIPMENT REMOVALS	A03,A04,A07,A10,A26,A27,Ø08,Ø11,Ø27,E02,E18,E19,E20,M03,M07,M08,M11,M12,M13,M14,M17,M24,M25,M29,G08
	UNSCHEDULED EQUIP. REMOVALS	A03,A04,A07,A10,A26,A27,Ø08,Ø11,Ø27,E02,E18,E19,E20
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	A02,A03,A04,A05,A27,G08
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A02,A03,A04,A15,A19,Ø24,E30,M02,M06,M07,M11,M12,M13,M14,M29,G06,G08

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

SHEET 1

TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
HORIZONTAL SITUATION INDICATOR	MAINTENANCE ACTION DEMAND	A07,A10,A16,A18,A21,A22,Ø08,Ø10,Ø14,Ø32,Ø33,E04,E13,E20,M03,M07,M08,M09,M10,M11,M12,M13,M14,M16,M17,M20,M22,M23,M24,M25,M28,M30,G02,G03,G04,G05,G07,G10,G11,G12,G16
	MAINTENANCE MANHOURS EXPENDED	A10,A18,A22,Ø10,Ø14,Ø32,Ø33,E04,E13,E20,M03,M07,M08,M09,M10,M11,M12,M13,M14,M15,M16,M17,M22,M23,M24,M25,M30,G03,G04,G05,G07,G11,G12
	TOTAL EQUIPMENT REMOVALS	A07,A13,Ø06,Ø08,Ø10,Ø14,Ø15,Ø32,Ø33,E05,E13,M03,M10,M13,M17,M20,M22,M23,M25,M28,M30,G02,G03,G04,G05,G07,G09,G11,G12,G15,G16
	UNSCHEDULED EQUIP. REMOVALS	A07,A13,Ø06,Ø08,Ø10,Ø14,Ø15,Ø32,Ø33,E04,E13
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A02,A04,A05,A08,A14,Ø03,Ø10,Ø12,Ø16,Ø34,E17,E19,E30,M02,M03
AUTOPILOT	MAINTENANCE ACTION DEMAND	A03,A04,A06,A08,A11,A13,A19,A21,A22,A27,Ø06,Ø08,Ø14,Ø23,Ø32,Ø33,E08,E13,E18,E23,E24,E26,E27,M03,M07,M08,M11,M12,M13,M14,M17,M20,M22,M23,M28,M29,M30,G03,G04,G05,G07,G08,G09,G11,G12,G15,G16
	MAINTENANCE MANHOURS EXPENDED	A03,A04,A06,A08,A11,A22,A27,Ø05,Ø23,E08,E16,E21,E23,E26,E27,M03,M07,M12,M13,M14,M20,M29,G08,G09
	TOTAL EQUIPMENT REMOVALS	A03,A04,A06,A08,A11,A13,A19,A27,Ø06,Ø08,Ø14,Ø23,Ø32,Ø33,E06,E07,E08,E13,E18,E19,E26,E27,M03,M07,M08,M11,M12,M13,M14,M17,M20,M22,M23,M28,M29,M30,G03,G04,G05,G07,G08,G09,G11,G12
	UNSCHEDULED EQUIP. REMOVALS	A03,A04,A06,A08,A11,A13,A19,A27,Ø06,Ø08,Ø13,Ø14,Ø23,Ø32,Ø33,E06,E07,E08,E13,E18,E19,E25,E26,E27
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	A05,A12,Ø14,Ø32,E30,M02,M04,G02,G03,G04,G05,G06,G07
	EQUIPMENT CANNIBALIZATION	A19,Ø03,Ø07,Ø11,Ø15,Ø17,Ø27,M05,M06,M07,M08,M09,M10,M11,M12,M13,M14,M16,M17,M22,M23,M24,M29
UHF COMMUNICATION SET	MAINTENANCE ACTION DEMAND	A03,A04,A10,A19,A21,A22,Ø02,Ø14,Ø18,Ø22,Ø27,Ø28,Ø32,E13,E18,E19,E20,M07,M08,M11,M12,M13,M14,M17,M22,M23,M24,M25,M28,M30,G03,G04,G05,G09,G11,G12
	MAINTENANCE MANHOURS EXPENDED	A03,A10,A22,Ø08,Ø11,Ø14,Ø15,Ø17,Ø18,Ø22,Ø25,Ø27,Ø32,E03,E13,E18,E19,E20,M03,M07,M08,M09,M10,M11,M12,M13,M14,M17,M22,M23,M24,M25,G03,G05,G12
	TOTAL EQUIPMENT REMOVALS	A03,A04,A19,Ø02,Ø08,Ø10,Ø14,Ø15,Ø17,Ø18,Ø22,Ø32,E04,E13,E18,E20,M04,M07,M08,M14,M17,M22,M23,M24,M25,M28,M30,G02,G03,G04,G05,G07,G09,G11,G12,G16
	UNSCHEDULED EQUIP. REMOVALS	A03,A04,A19,Ø02,Ø08,Ø10,Ø14,Ø15,Ø17,Ø18,Ø22,Ø32,E04,E13,E18,E20
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	Ø03,Ø07,Ø12,Ø16,Ø19,Ø20,Ø22,Ø24,Ø26,Ø29
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A05,A09,A15,Ø26,Ø35,E09,E12,E16,E17,E30,E31

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
IFF TRANSPONDER SET	MAINTENANCE ACTION DEMAND	A02,A05,A09,A21,A23,Ø03,Ø05,Ø09,Ø13,E06,E12,E13,E31,M07,M11,M12,M13,M14,M17,M28,M29
	MAINTENANCE MANHOURS EXPENDED	A02,A03,A14,Ø11,E16,E19,E21,E30,M07,M09,M11,M12,M13,M14,M16,M27,M29,G06,G08
	TOTAL EQUIPMENT REMOVALS	A02,A05,A09,A21,Ø05,Ø12,E19,M27,M28,M29,G08
	UNSCHEDULED EQUIP. REMOVALS	A02,A05,A09,A21,Ø05,Ø12,E19
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A02,A03,A11,A14,A21,A22,Ø05,M29
INERTIAL NAVIGATION SET	MAINTENANCE ACTION DEMAND	A02,A03,A04,A05,A06,A07,A13,A21,A22,A27,Ø05,Ø09,Ø13,Ø25,Ø30,Ø34,E14,E16,E21,G06,G08,G15
	MAINTENANCE MANHOURS EXPENDED	A04,A05,A07,A13,A22,A27,Ø05,Ø19,Ø25,Ø34,E17,E21,G06,G08,G15
	TOTAL EQUIPMENT REMOVALS	A03,A04,A05,A06,A07,A13,Ø05,Ø19,Ø34,G06,G08
	UNSCHEDULED EQUIP. REMOVALS	A03,A04,A05,A06,A07,A13,A27,Ø05,Ø34,E16,E21
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	A06,A08,A12,A15,A16
	EQUIPMENT CANNIBALIZATION	A02,A03,A04,A05,A06,A12,A15,A18,Ø05,Ø25,Ø31,Ø34,E05,G15
INSTRUMENT LANDING SET	MAINTENANCE ACTION DEMAND	A02,A06,A10,A15,A21,A22,Ø15,Ø25,Ø27,Ø32,E03,E09,E19,E20,M05,M07,M08,M09,M10,M11,M12,M13,M14,M15,M16,M17,M22,M23,M24,M25, G14
	MAINTENANCE MANHOURS EXPENDED	A02,A06,A08,A10,A11,A22,A27,E02,E19,M07,M08,M09,M10,M11,M12,M13,M14,M15,M16,M17,M23,M26,M27,M29,G08
	TOTAL EQUIPMENT REMOVALS	A06,A15,Ø15,Ø32,E17,E19,M07,M08,M09,M10,M11,M12,M13,M14,M15,M16,M17,M22,M23,M24,M25,G14
	UNSCHEDULED EQUIP. REMOVALS	A06,A15,Ø15,Ø32,E17,E19,E20
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A02,A06,A08,A10,A11,M07,M11,M12,M13,M14,M16,M27,M29,G08

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
TACAN SET	MAINTENANCE ACTION DEMAND	A02,A03,A12,A18,A19,A21,A22,Ø15,Ø27,Ø32,E13,E18,E19,E20,M07,M08,M09,M10,M11,M12,M13,M14,M17,M22,M23,M24,M25,M28,G03,G04, G05,G11,G12
	MAINTENANCE MANHOURS EXPENDED	A02,A08,A18,A22,Ø08,Ø15,Ø25,Ø27,Ø32,E03,E13,E18,E19,E20,M07,M08,M09,M10,M11,M12,M13,M14,M17,M22,M23,M24,M25,G03,G05,G12
	TOTAL EQUIPMENT REMOVALS	A03,A12,A16,A18,A19,Ø08,Ø15,Ø27,Ø32,E13,E18,E19,E20,M07,M08,M09,M10,M11,M12,M13,M14,M17,M22,M23,M24,M25,M28,M30,G03,G04, G05,G07,G09,G11,G12
	UNSCHEDULED EQUIP. REMOVALS	A03,A12,A18,A19,Ø08,Ø15,Ø27,Ø32,E13,E18,E19,E20
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	A15,A18,Ø35,E30,E31
ATTITUDE-HEADING REFERENCE SET	MAINTENANCE ACTION DEMAND	A04,A05,A06,A08,A21,A22,Ø09,Ø12,Ø13,E27,M05,M06,M20,M27,M29,G08,G15
	MAINTENANCE MANHOURS EXPENDED	A22,A27,Ø05,E16,E21,E30,M02,M03,G06,G08,G15
	TOTAL EQUIPMENT REMOVALS	A04,A06,A08,Ø05,Ø27,E27,M05,M10,M20,M29,G08,G15
	UNSCHEDULED EQUIP. REMOVALS	A04,A06,A08,Ø05,Ø27,E27
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	Ø33,G08
RADAR SET	MAINTENANCE ACTION DEMAND	A02,A03,A10,A12,A13,A19,A21,A22,Ø05,Ø10,Ø11,Ø14,Ø15,Ø19,Ø32,E03,E13,E16,E18,E20,M11,M12,M13,M14,M16,M17,M22,M23,M24,M25, M28,M29,G02,G03,G04,G05,G11,G12
	MAINTENANCE MANHOURS EXPENDED	A02,A03,A04,A15,A18,A22,Ø05,Ø07,Ø10,Ø12,Ø15,Ø24,Ø34,E13,E16,E17,E30,M02,M03,M16,M17,M20,M23,M29,G11,G12,G15
	TOTAL EQUIPMENT REMOVALS	A02,A03,A04,A10,A12,A13,A15,A16,A18,Ø05,Ø10,Ø12,Ø15,Ø24,Ø34,E13,E16,E17,E20,E30,M02,M03,M07,M11,M12,M13,M14,M16,M17,M22, M23,M28,M29,G03,G11,G12,G15,G16
	UNSCHEDULED EQUIP. REMOVALS	A02,A03,A04,A12,A13,A15,A16,A18,Ø05,Ø10,Ø12,Ø13,Ø15,E13,E16,E17,E23,E30
	SCHEDULED EQUIP. REMOVALS	None
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
RADOMES	MAINTENANCE ACTION DEMAND	R03,F08,Ø03,Ø05,Ø07,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E02,E03,E14,E18,E19,E20,M05,M06,M07,M08,M09,M10,M17,M21,M22,M23,M24,M25
	MAINTENANCE MANHOURS EXPENDED	R04,F03,F24,Ø05,Ø11,Ø12,Ø15,Ø17,Ø19,Ø21,Ø25,Ø27,Ø31,Ø34,E02,E03,E06,E07,E08,E09,E14,E18,E19,E20,E21,E22,E23,E24,E27,M04,M08,M17,M24,M25,G15
	UNSCHEDULED EQUIPMENT REMOVALS	F08,F24,Ø05,Ø11,Ø12,Ø17,Ø19,Ø21,Ø25,Ø27,Ø31,E02,E03,E18,E19,E20,M05,M07,M08,M09,M10,M17,M22,M23,M24,M25,G14,G15
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None
WINDSHIELDS	MAINTENANCE ACTION DEMAND	R02,R03,F03,F04,F07,Ø08,Ø11,Ø12,Ø15,Ø17,Ø21,Ø27,E13,E18,E19,E20,M07,M08,M10,M17,M22,M23,M24,M25,G12,G14
	MAINTENANCE MANHOURS EXPENDED	R03,F03,F04,F07,F16,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E03,E09,E13,E18,E19,E20,M03,M05,M06,M07,M08,M09,M10,M17,M22,M23,M24,M25,G12,G14
	UNSCHEDULED EQUIPMENT REMOVALS	F03,F04,F07,F16,Ø11,Ø12,Ø15,Ø17,Ø18,Ø21,Ø25,Ø27,E03,E09,E13,E18,E19,E20,M03,M05,M06,M07,M08,M09,M10,M17,M22,M23,M24,M25,G12
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	E04,E11,E13,E16,E23,M28,M29
WINGS	MAINTENANCE ACTION DEMAND	R02,R03,F04,F07,Ø02,Ø08,Ø10,Ø11,Ø12,Ø14,Ø15,Ø17,Ø21,Ø27,Ø32,E13,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25,M28,G03,G04,G05,G09,G11,G12,G14
	MAINTENANCE MANHOURS EXPENDED	R03,F04,F07,Ø08,Ø11,Ø12,Ø14,Ø15,Ø17,Ø21,Ø25,Ø27,Ø32,E03,E13,E18,E19,E20,E21,M05,M07,M08,M09,M10,M17,M22,M23,M24,M25,G03,G04,G05,G11,G12,G14
	UNSCHEDULED EQUIPMENT REMOVALS	F04,F07,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E02,E03,E18,E19,E20,M05,M07,M08,M09,M10,M17,M22,M23,M24,M25,G14
	AIR ABORTS	None
	GROUND ABORTS	F07,Ø08,Ø09,Ø12,Ø26,Ø30,Ø31,Ø33
	EQUIPMENT CANNIBALIZATION	Ø05,Ø06,Ø09,Ø17,Ø21,Ø27,Ø31,E02,E04,E05,E07,E14,E17,E21,E30,M05,M07,M08,M10,G15
COCKPIT FURNISHINGS	MAINTENANCE ACTION DEMAND	R02,R03,R05,F06,F07,F08,F11,Ø08,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E02,E03,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25,G14
	MAINTENANCE MANHOURS EXPENDED	R03,F11,F13,Ø05,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E03,E09,E14,E18,E19,E20,M07,M08,M10,M24,M25,G15
	UNSCHEDULED EQUIPMENT REMOVALS	R05,F06,F07,F08,F11,Ø11,Ø12,Ø15,Ø17,Ø19,Ø21,Ø25,Ø27,E03,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25,G14
	AIR ABORTS	F11
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
LANDING GEAR	MAINTENANCE ACTION DEMAND	R02,R03,F03,F04,F06,F08,F13,F16,F22,Ø08,Ø10,Ø14,Ø15,Ø16,Ø19,Ø21,Ø32,E03,E04,E13,E18,E20,E21,M03,M07,M08,M10,M17,M22,M23,M24,M25,M28,M30,G02,G05,G06,G07,G08,G09,G10,G11,G12,G14,G16
	MAINTENANCE MANHOURS EXPENDED	F03,F04,F13,F22,Ø02,Ø06,Ø08,Ø14,Ø16,Ø32,Ø33,E13,E14,E20,E21,M03,M04,M17,M20,M22,M23,M25,M28,M30,G02,G03,G04,G05,G06,G07 G09,G10,G11,G12,G14,G16
	UNSCHEDULED EQUIPMENT REMOVALS	F06,F08,F13,F16,F17,Ø07,Ø09,Ø13,Ø16,Ø19,Ø20,Ø25,Ø26,Ø29,E03,M21,M26,G13
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None
BRAKES	MAINTENANCE ACTION DEMAND	R02,R03,F09,Ø03,Ø05,Ø09,Ø16,Ø20,Ø26,Ø31,E03,E16,M03,M29
	MAINTENANCE MANHOURS EXPENDED	R03,R06,F02,F08,F11,F13,Ø05,Ø07,Ø09,Ø13,Ø16,Ø20,Ø26,Ø29,Ø30,Ø31,E16,E30,M02,M21,M29,G06,G13
	UNSCHEDULED EQUIPMENT REMOVALS	F02,F11,Ø03,Ø09,Ø13,Ø16,Ø19,Ø20,Ø26,Ø30,Ø31,E03,E16,E17,E25,E31,M02,M03,G13
	AIR ABORTS	None
	GROUND ABORTS	F03,F04,F11,F13,Ø06,Ø07,Ø08,Ø12,Ø14,Ø20,Ø29,E04,E10,E13,E15,E17,E18,E30,M02,M03,M22,M23
	EQUIPMENT CANNIBALIZATION	F04,F13,Ø03,Ø07,Ø12,Ø16,Ø19,Ø20,Ø26,Ø29,E26,M05,M07,M08,M09,M10,M21,M25
STABILATOR	MAINTENANCE ACTION DEMAND	R02,R03,F03,F06,Ø08,Ø11,Ø12,Ø15,Ø17,Ø21,Ø27,E03,E13,E18,E19,E20,M07,M08,M10,M17,M22,M23,M24,M25,M28,G14
	MAINTENANCE MANHOURS EXPENDED	R02,R06,F02,F03,F15,Ø11,Ø15,Ø17,Ø21,E02,E18,E19,E20,M07,M08,M17,M27,M29,G08
	UNSCHEDULED EQUIPMENT REMOVALS	R06,F03,Ø11,Ø21,E02,E18,E19,E24,M07,M08,M24,G08
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	F07,E16,E19,E24,M29,G06,G08
RUDDER	MAINTENANCE ACTION DEMAND	R02,R03,Ø11,Ø12,Ø15,Ø17,Ø18,Ø21,Ø25,Ø27,Ø34,E03,E09,E18,E19,E20,E24,E27,M05,M07,M08,M10,M17,M22,M23,M24,M25
	MAINTENANCE MANHOURS EXPENDED	R03,Ø11,Ø15,Ø17,Ø18,Ø21,Ø25,Ø34,Ø35,E03,E09,E14,E18,E19,E20,E27,E30,M05,M07,M08,M24
	UNSCHEDULED EQUIPMENT REMOVALS	Ø11,Ø25,Ø35,E03,E06,E09,E10,E12,E14,E15,E23,E24,E25,E26,E27,E28,E30,E31,M02,M03,M05,M06,M07,M08,M24
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
FLAPS	MAINTENANCE ACTION DEMAND	R02,R03,R06,F03,F04,F06,F08,F10,Ø08,Ø11,Ø15,Ø17,Ø21,Ø27,E18,E19,E20,M07,M08,M10,M17,M22,M23,M24,M25,M27,M28,M29,G08
	MAINTENANCE MANHOURS EXPENDED	R03,R06,F03,F04,F08,F10,Ø08,Ø11,Ø12,Ø15,Ø17,Ø21,Ø27,E03,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25,G12,G14
	UNSCHEDULED EQUIPMENT REMOVALS	F03,F04,F08,Ø08,Ø11,Ø12,Ø15,Ø17,Ø21,Ø27,E02,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	F06,F10,E07,E16,E18,E19,E21,E24,E27,M07,M29,G08
ENVIRONMENTAL CONTROL SYSTEM	MAINTENANCE ACTION DEMAND	R02,R03,R06,F08,E02,E19,E24,M29,G08
	MAINTENANCE MANHOURS EXPENDED	R03,R06,F08,F17,Ø05,E07,E16,E19,E21,E24,M29,G06,G08
	UNSCHEDULED EQUIPMENT REMOVALS	F17,Ø05,Ø12,Ø29,E19,E24,M27,M29,G06,G08
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	F16,Ø11,Ø12,Ø15,Ø17,Ø21,Ø25,Ø27,E02,E03,E18,E19,E20,M07,M08,M10,M17,M22,M23,M24,M25
ELECTRICAL POWER SYSTEM	MAINTENANCE ACTION DEMAND	R02,R04,F07,F09,F10,F13,Ø02,Ø03,Ø05,Ø06,Ø07,Ø08,Ø14,Ø16,Ø32,Ø33,Ø35,E14,M04,M05,M06,M20,M28,M30,G02,G03,G04,G05,G07,G09,G10,G11,G12,G14,G16
	MAINTENANCE MANHOURS EXPENDED	R03,R04,F05,F07,F09,Ø05,Ø08,E07,E19,E24,M07,M17,M20,M27,M28,M29,G02,G08,G09,G16
	UNSCHEDULED EQUIPMENT REMOVALS	F05,F06,F09,Ø09,Ø10,Ø11,Ø15,Ø17,Ø21,Ø27,Ø32,E13,E18,E19,E20,E26,M07,M08,M09,M10,M17,M22,M23,M24,M25,M28,G03,G05,G12,G15
	AIR ABORTS	None
	GROUND ABORTS	F05,Ø05,Ø07,Ø12,Ø20,Ø29,Ø30,M05,M06,M20,M21,M27,M28
	EQUIPMENT CANNIBALIZATION	F05,F16,Ø05,Ø09,Ø30,Ø31,E17,M02,M04,G13,G15
NAVIGATION LIGHTS	MAINTENANCE ACTION DEMAND	R02,R03,F03,F04,F06,F08,F11,Ø11,Ø15,Ø17,Ø21,Ø25,Ø27,E02,E03,E16,E18,E19,E20,E30,M03,M05,M07,M08,M09,M10,M17,M24,M25,M29
	MAINTENANCE MANHOURS EXPENDED	R03,R06,F03,F04,F06,F08,F11,Ø11,Ø15,Ø17,Ø21,Ø27,E02,E03,E16,E18,E19,E20,M07,M08,M09,M10,M17,M24,M27,M29,G08
	UNSCHEDULED EQUIPMENT REMOVALS	R06,F03,F04,F06,F08,F11,Ø11,Ø15,Ø17,Ø21,Ø27,E02,E03,E18,E19,E20,M07,M08,M09,M10,M17,M24,M27,M29,G08
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	E07,E16,E19,E21,E24,E27,M29,G06,G08

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
LANDING/TAXI LIGHTS	MAINTENANCE ACTION DEMAND	R02,R03,F03,F04,F13,Ø08,Ø11,Ø15,Ø17,Ø21,Ø27,E18,E19,E20,M07,M08,M09,M10,M17,M22,M23,M24,M25,M29,G08,G12,G14
	MAINTENANCE MANHOURS EXPENDED	R03,F03,F04,Ø08,Ø11,Ø15,Ø17,Ø18,Ø21,Ø25,Ø27,E02,E03,E18,E19,E20,M07,M08,M10,M17,M22,M23,M24,M25,M28,G14
	UNSCHEDULED EQUIPMENT REMOVALS	F08,Ø11,Ø21,E02,E16,E18,E19,E24,M07,M08,M15,M29,G08
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	Ø05,Ø30,E16,E21,E24,G06,G08
HYDRAULIC POWER SYSTEM	MAINTENANCE ACTION DEMAND	R02,R03,F04,F11,Ø05,Ø06,Ø08,Ø14,Ø25,Ø32,Ø33,E06,E07,E08,E14,E23,E24,E26,E27,M20,M29,M30,G02,G03,G04,G05,G07,G08,G09,G10,G11,G15,G16
	MAINTENANCE MANHOURS EXPENDED	R03,F11,Ø02,Ø05,Ø06,Ø08,Ø14,Ø32,Ø33,E04,E06,E07,E08,E13,E14,E16,E23,E24,E26,E27,M20,M28,M29,M30,G02,G03,G04,G05,G07,G08,G09,G10,G11,G12,G15,G16
	UNSCHEDULED EQUIPMENT REMOVALS	F04,F11,Ø02,Ø03,Ø05,Ø06,Ø08,Ø12,Ø14,Ø16,Ø25,Ø27,Ø32,Ø33,E02,E06,E07,E08,E14,E23,E24,E27,M03,M09,M20,M30,G02,G03,G04,G07,G08,G09,G10,G11,G15,G16
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None
INTERNAL FUEL SYSTEM	MAINTENANCE ACTION DEMAND	R02,F16,Ø10,Ø11,Ø15,Ø17,Ø21,Ø27,E13,E16,E18,E19,E20,E23,E26,M07,M08,M09,M10,M17,M24,M27,M29,G08,G12
	MAINTENANCE MANHOURS EXPENDED	Ø05,Ø08,Ø14,Ø25,Ø33,E06,E07,E08,E13,E14,E16,E21,E23,E24,E26,E27,M20,M27,M29,G08,G09,G15
	UNSCHEDULED EQUIPMENT REMOVALS	F04,Ø03,Ø05,Ø06,Ø09,Ø13,Ø14,Ø16,Ø32,Ø33,Ø34,E02,E06,E07,E08,E13,E14,E17,E19,M03,M20,M30,G03,G04,G05,G07,G09,G10,G11,G12,G15,G16
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None
OXYGEN SYSTEM	MAINTENANCE ACTION DEMAND	R03,R06,F03,Ø05,Ø30,E06,E07,E16,E21,E23,E24,E27,E28,M27,M29,G06,G08
	MAINTENANCE MANHOURS EXPENDED	F09,F11,Ø08,Ø09,Ø10,Ø13,Ø30,Ø31,E09,E15,E25,E28,E30,E31,M04,G06,G13
	UNSCHEDULED EQUIPMENT REMOVALS	F04,F09,F11,Ø05,Ø08,Ø09,Ø12,Ø30,Ø31,E09,E21,E25,E28,E30,E31,M04,G06,G13
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	E07,E19,E21,E24,E27,M27,M29,G06,G09

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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TABLE 15 SIGNIFICANT MAINTENANCE IMPACT RELATIONSHIPS DETECTED

SUBSYSTEM	MAINTENANCE RESOURCE DEMAND	SIGNIFICANT IMPACTING PARAMETERS*
LOX SYSTEM	MAINTENANCE ACTION DEMAND	R02,R03,F04,F08,F17,Ø05,Ø06,Ø08,Ø14,Ø32,Ø33,Ø34,E06,E07,E08,E14,E23,E24,E27,M03,M20,M22,M23,M28,M29,M30,G02,G03,G04,G05,G07,G08,G09,G10,G11,G12,G14,G15,G16
	MAINTENANCE MANHOURS EXPENDED	R03,F04,F08,F09,Ø05,Ø09,Ø14,Ø32,Ø33,Ø34,E06,E07,E08,E12,E13,E14,E23,E24,E26,E27,E28,E31,M17,M20,M22,M23,M28,M29,M30,G03,G04,G05,G07,G08,G09,G10,G11,G12,G14,G15
	UNSCHEDULED EQUIPMENT REMOVALS	F04,F08,Ø05,Ø33,Ø34,E06,E07,E08,E23,E24,E26,E27,M20,M27,M29,G08,G09,G15
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	F01,F03,F17,Ø10,E02,E10,E21,E24,M25,M27,G06,G08
ENGINE FIRE DETECTION	MAINTENANCE ACTION DEMAND	R02,R03,F03,F04,F08,E07,E16,E18,E19,E21,E23,E24,E27,M07,M08,M17,M27,M29,G08
	MAINTENANCE MANHOURS EXPENDED	R03,F06,Ø05,Ø09,Ø30,Ø31,E06,E07,E16,E21,E23,E24,E26,E27,E30,M02,M27,M29,G06,G08
	UNSCHEDULED EQUIPMENT REMOVALS	F04,Ø05,Ø30,E02,E16,E19,E21,E24,E27,M27,M29,G06,G08
	AIR ABORTS	None
	GROUND ABORTS	None
	EQUIPMENT CANNIBALIZATION	None

* KEY TO IMPACTING PARAMETER NUMBERS GIVEN IN TABLE 14

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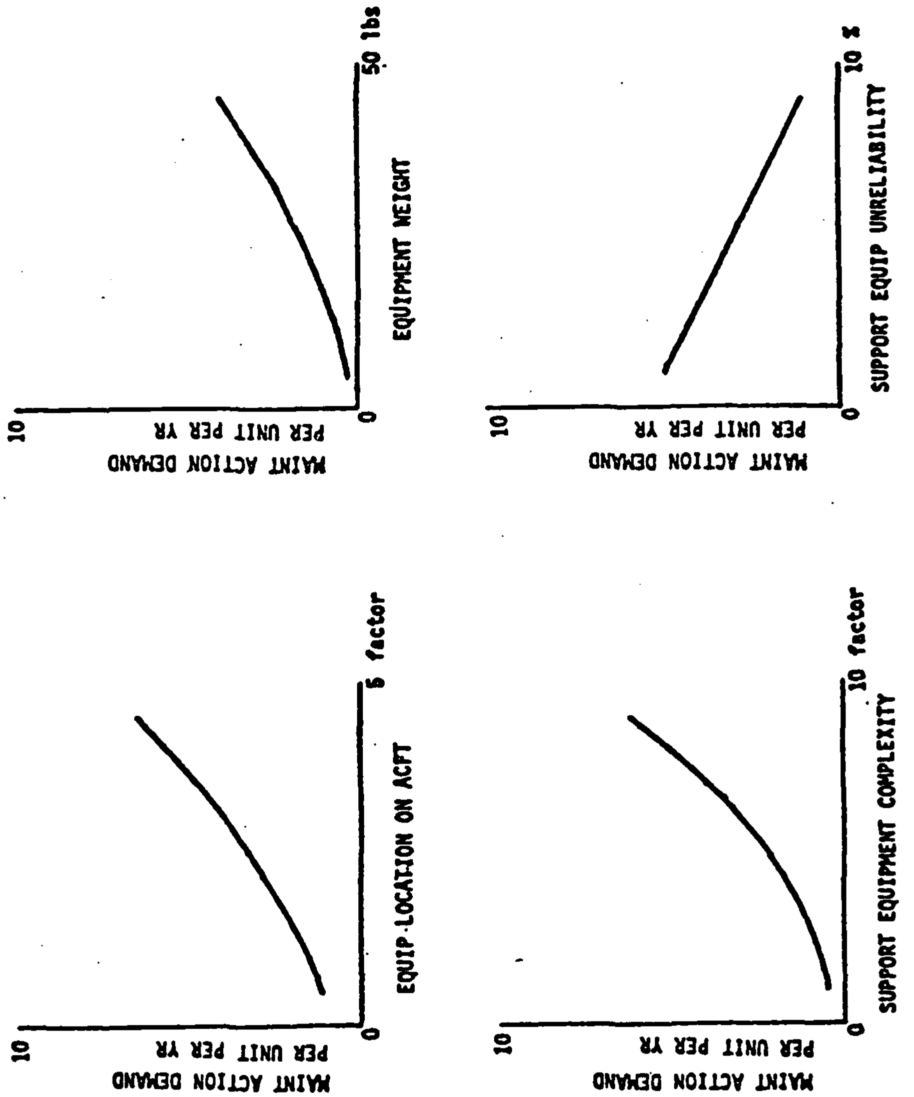

FIGURE 13 TYPICAL MIER'S (TACAN SET)

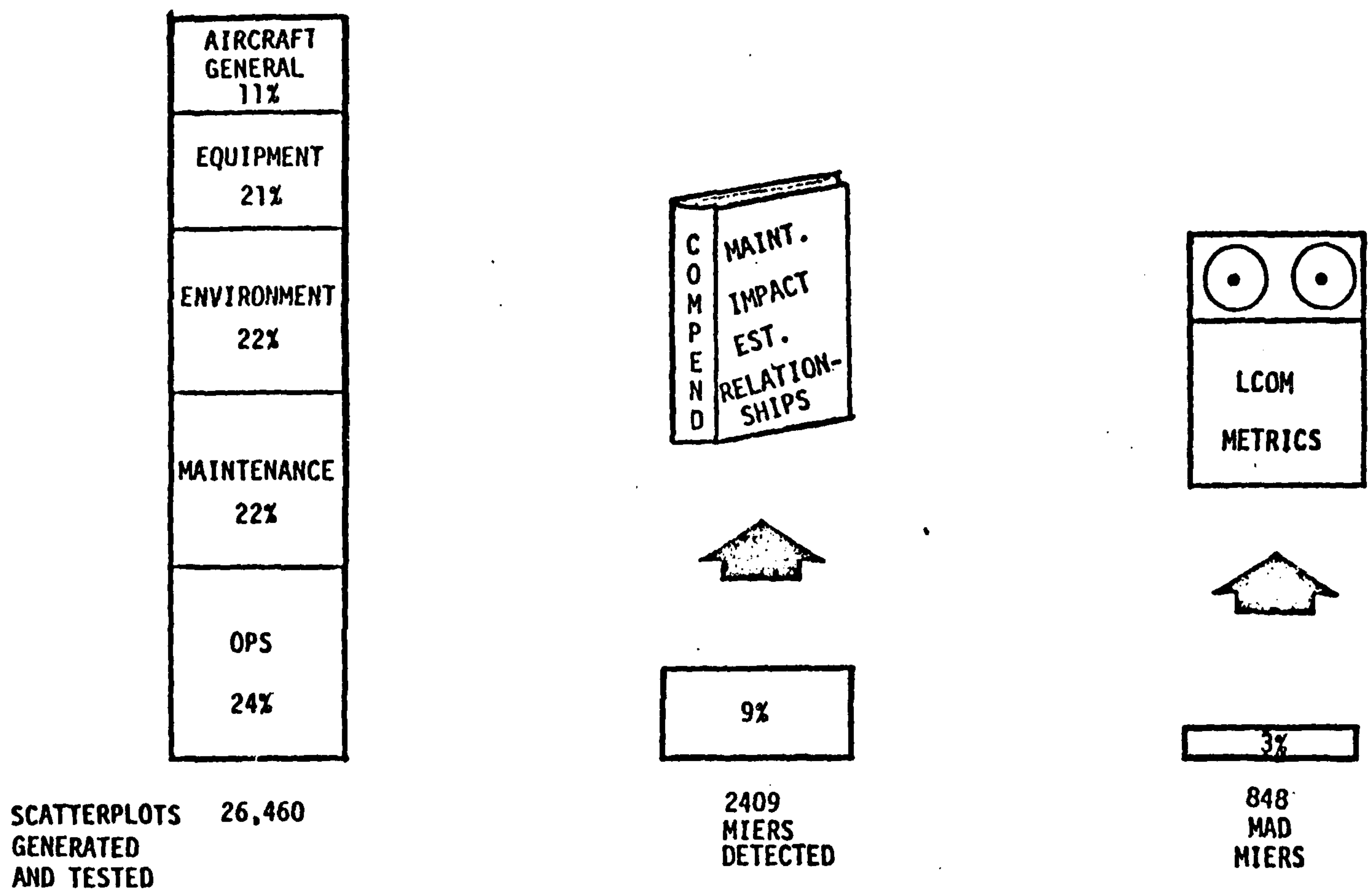

FIGURE 14 NUMBER OF MIER'S DETECTED AND RETAINED

7.0 DEVELOPMENT OF MAINTENANCE METRICS AND WEIGHTINGS MODELS - TASKS VI AND VII

Tasks VI and VII were the development of new comprehensive prediction and estimation models for maintenance action rates from the field experience and analytical data base accumulated by the first five study tasks. The objective of this model development effort is the improvement of the estimation techniques currently used to predict the maintenance metrics of emerging weapon systems and/or new basing concepts. Task VI was originally intended to be an effort which utilized the design, packaging environment, and use characteristics of the equipment items studied to develop statistical mathematic or parametric models for the estimation of the resource demands of each study subsystem. Task VII was intended to develop statistical weighting factors with which to appropriately modify model estimation results to compensate for specific aircraft basing concepts operational and environmental conditions.

Study Task VI/VII contained two distinct subefforts. The first was to develop the necessary maintenance metrics to predict subsystem maintenance action demand. The second effort was the development of means for estimating lower level task selection probabilities within a particular maintenance action. That is, estimation of the probability of whether the maintenance action will take place "on equipment" or "off equipment," and the respective probabilities of the various alternatives within these two categories. Figure 15 depicts the general analytical approach divided into the related subtasks which were necessary to accomplish the above two subefforts. Complete details and data pertaining to Task VI/VII study efforts are contained in Boeing Interim Technical Report D194-10089-3 (Reference 17) and are summarized in the remainder of Section 7.

The approach taken for the first portion of the Task VI/VII study effort (subtasks 6&7.1 - 6&7.7) was to utilize the source data assembled during Task IV (Section 5.0) for the significant correlates identified in Task V (Section 6.0) as inputs to develop statistical models for the estimation and prediction of the maintenance action demands of the equipment items selected for study. The data-case values acquired for the lists of equipment, operational, and environmental parameters which were found in Task V (Analyzing and Prioritizing Parameters) to be directly and strongly related to the maintenance demand rates of the selected equipment items were reconstituted into input data sets for the modeling process (6&7.1 and 6&7.2). This process resulted in one equipment, one operational, and one environmental data set being associated with each aircraft subsystem studied. Step-wise regression analysis was then applied to each data set for each subsystem's equipment to obtain "best fit" multiple regression equations explaining maintenance action demand as a function of equipment characteristic parameters, as a function of operational characteristic parameters, and as a function of environmental characteristic parameters (6&7.3). These separate equations for each type of parameter constitute "generic" Maintenance Metrics and

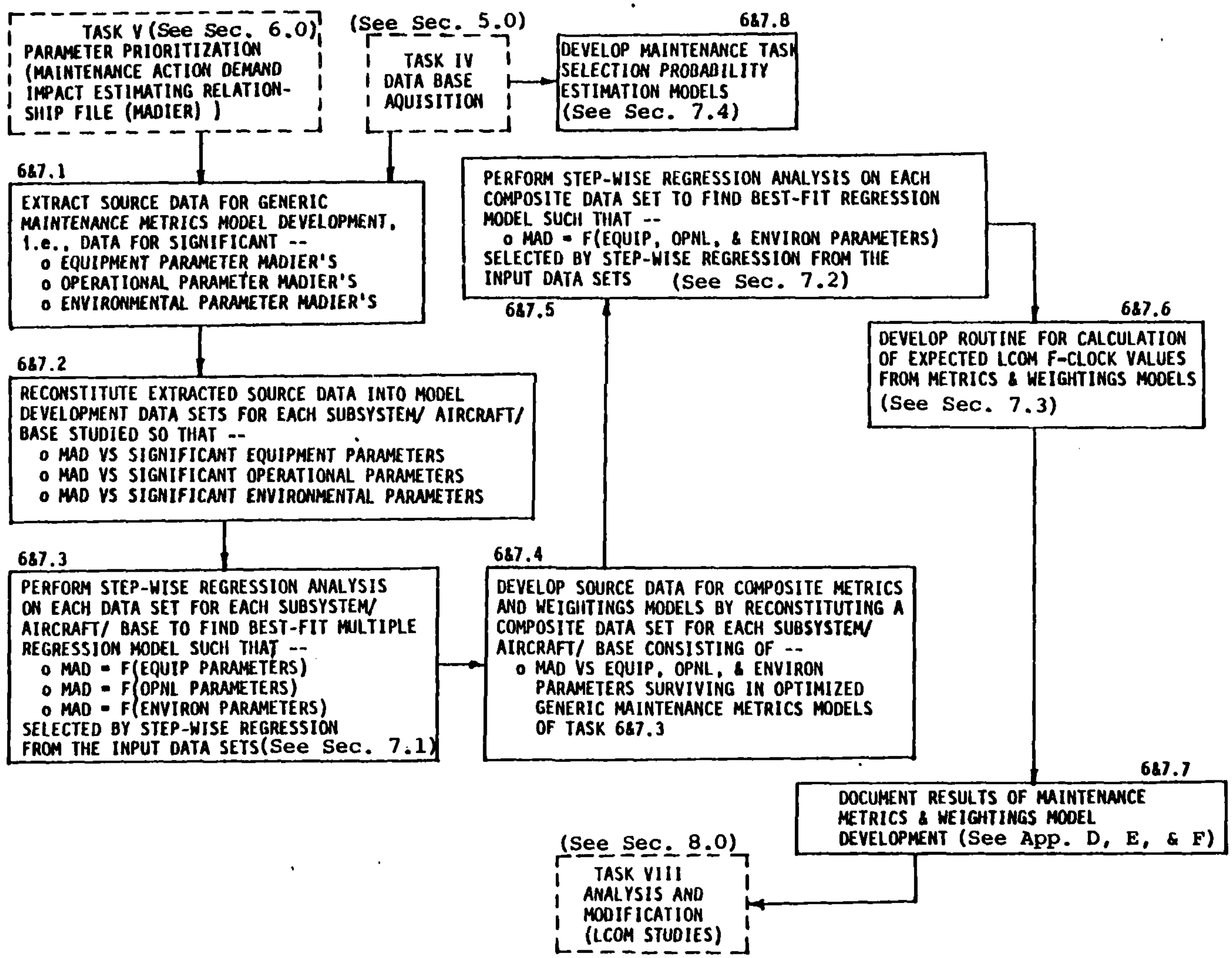

FIGURE 15 TASKS VI AND VII PROCESS FLOW

Weightings Models which facilitate the estimation of expected maintenance action demand for any aircraft subsystem when only equipment characteristics, only operational characteristics, or only environmental characteristics are known. The preparation, execttion, and results of the above three subtasks are discussed in Subsection 7.1. Summary documentation of these models (6&7.7) is contained in Appendix D.

Next, "composite" Maintenance Metrics and Weightings Models were developed from the generic models for each aircraft subsystem. The following approach was utilized. The component parameters in the respective generic equipment, operational, and environmental regression equations for each subsystem were reconstituted into a composite data set corresponding to each subsystem (6&7.4). Step-wise regression was applied to these composite data sets (6&7.5). This process resulted in a "best fit" estimating equation to explain the expected maintenance action demand of each aircraft subsystem in terms of the equipment, operational, and environmental parameters selected from the corresponding composite data set by the step-wise regression process. These composite models provide a more accurate statistical estimation of the maintenance demand for a given subsystem than any of the three types of generic models used singly. The composite models should therefore be used to predict maintenance action rates whenever the appropriate equipment, operational, and environmental data can be obtained. The accomplishment and results of the composite model development effort are discussed in Subsection 7.2. Documentation of these models (6&7.7) is contained in Appendix E.

The maintenance action demand estimating models developed through the above efforts are useful for the prediction of the various study subsystems' maintenance action rates under new equipment design conditions, new environmental conditions, and/or new operational scenarios. One intended use of the products of Task VI/VII is the improvement of input values for LCOM maintenance network failure clock when simulating new systems and situations. To this end, a routine was developed for the calculation of these expected LCOM F-clock values from the outputs of the maintenance action demand estimating models discussed above. This effort is depicted in Subsection 7.3. Appendix F contains a completed example of the F-clock calculation routine.

The last subtask (6&7.8) for the metrics and weightings development effort was the development of an estimation procedure for LCOM maintenance network task selection probabilities. The approach taken for this task was a straightforward averaging method using historic task frequency data. Specific maintenance task frequencies were extracted from the study data base for each data case (aircraft/base combination) for each aircraft subsystem. The mean, median, and range of the frequency of performance for each task for each subsystem was then computed. The results of this analysis facilitate the estimation of the LCOM maintenance network task selection probabilities for the simulation of new weapon systems and basing concepts. The subtask 6&7.8 effort and results are summarized in Subsection 7.4.

7.1 DEVELOPMENT OF GENERIC MAINTENANCE ACTION DEMAND ESTIMATING MODELS - SUBTASKS 6 & 7.1, 6 & 7.2, and 6 & 7.3

The first step in the process of development of comprehensive Maintenance Metrics and Weightings Models for aircraft systems was to explore the feasibility of generic estimation models whereby the maintenance action demand for a given subsystem could be predicted from just equipment characteristics, just operational characteristics, or just environmental characteristics. To this end, generic model development data sets were assembled. These data sets were extracted from the data base acquired through the processes of the first four study tasks, and are composed of the equipment, operational, and environmental parameters which were found to be significantly correlated with maintenance action demand during the course of Task V. Three generic significant-parameter data sets were assembled for each of the thirty aircraft subsystem equipments investigated.

Step-wise regression analysis was then applied to each of the significant-parameter data sets to find the "best fit" multiple regression equation to explain maintenance action demand in terms of some or all of the parameters included in each of the three data sets corresponding to each of the thirty aircraft subsystems analyzed. This effort resulted in the derivation of ninety regression equations for the estimation of --

- MAD as a function of Equipment Characteristic Parameters,
- MAD as a function of Operational Characteristic Parameters,
- MAD as a function of Environmental Characteristic Parameters,

the ninety equations comprised one set of three equations for each of the thirty subsystems. An interactive computer technique was utilized to develop the above referenced equations. The program package used was Boeing Computer Services "Conversational Terminal System" statistical program package (STAT PACK), stepwise regression subroutine (Reference 16). This program allows the analyst to experiment freely with the choice of independent variables to be included in the regression equation and thus find an optimum fit of the data in terms of multiple correlation coefficient, standard error of the estimate, and the T-statistics of the included variables. The general procedure used in the development of the three categories of generic models as well as the composite models discussed in following Subsection 7.2 is depicted by Figure 16. Table 16 lists the equipment characteristic parameters which enter each subsystem model in the "Equipment" generic model category. Tables 17 and 18 list the operational characteristic parameters and environmental characteristic parameters entering each

16 "Mainstream - CTS Interactive Statistical Package (STATPK)," Boeing Computer Services, Seattle, Washington, March 1978.

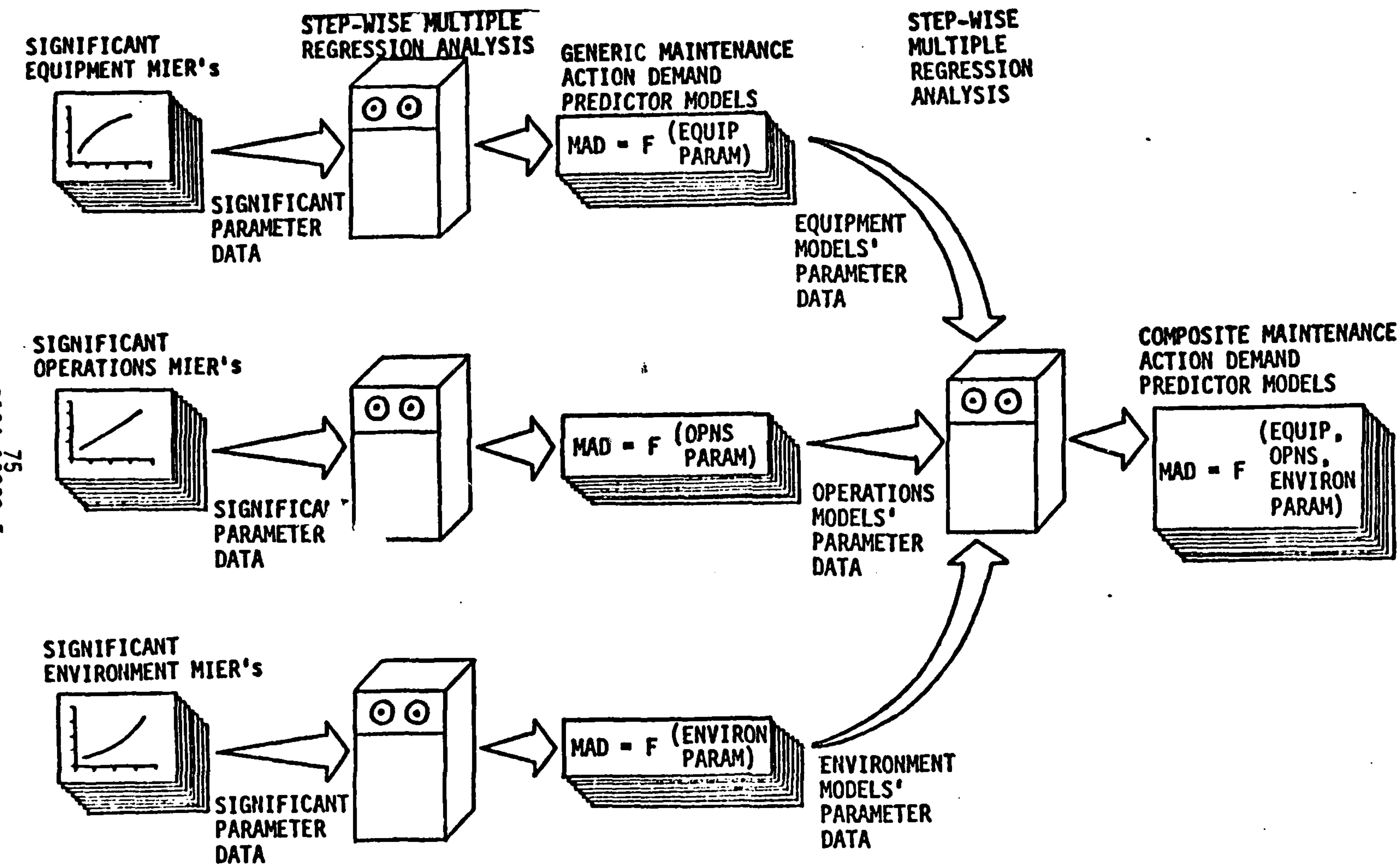

FIGURE 16 TASKS VI AND VII PROCESS FLOW

TABLE 16 SUBSYSTEM MAD AS A FUNCTION OF EQUIPMENT PARAMETERS ONLY
(Sheet 1)

SUBSYSTEM	EQUIPMENT PARAMETERS ENTERING MAD ESTIMATING EQUATION
Propulsion	P02 - Total Number of Installed Engines P04 - Weight per Engine
Flight Indicators	A03 - Equipment Weight
Air Data System	A03 - Equipment Weight A07 - Cooling Method A16 - On-Off Cycles per Flying Hour A19 - Failure Abort Ratio
Horizontal Situation Indicator	A07 - Cooling Method A16 - On-Off Cycles per Flying Hour A18 - Ground/Flight Operating Ratio
Autopilot	A03 - Equipment Weight A04 - Equipment Volume A08 - Protection Devices A13 - Average Operating Time per Sortie A19 - Failure/Abort Ratio
UHF Communications Set	A03 - Equipment Weight A04 - Equipment Volume A05 - SRU Count
IFF Transponder Set	A02 - Equipment Location on Aircraft A09 - Number of Test Points
Inertial Navigation Set	A05 - SRU Count
Instrument Landing Set	A02 - Equipment Location on Aircraft A06 - Operating Temperature A15-- Retest OK Rate
TACAN Set	A03 - Equipment Weight A18 - Ground/Flight Operating Ratio
Attitude-Heading Reference Set	A08 - Protection Devices A12 - AGE Unreliability

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 16 SUBSYSTEM MAD AS A FUNCTION OF EQUIPMENT PARAMETERS ONLY (Sheet 2)

SUBSYSTEM	EQUIPMENT PARAMETERS ENTERING MAD ESTIMATING EQUATION
Radar Set	A02 - Equipment Location on Aircraft A12 - AGE Unreliability A19 - Failure/Abort Ratio
Radome	F08 - Type of Failure
Windshield	F03 - Equipment Weight F07 - Support Equipment Reliability
Wings	F04 - Equipment Volume
Cockpit Furnishings	F11 - Ground/Flight Operating Ratio
Main Landing Gear	F03 - Equipment Weight F06 - Support Equipment Complexity F13 - Removals to Access Other Equipment F22 - Landings per Tire Allowed
Brakes	F09 - Flight Brake Squawk Verification Rate
Stabilator	F03 - Weight F06 - Support Equipment Complexity
Rudder	None (No Correlated Data)
Flaps	F03 - Equipment Weight F04 - Equipment Volume F06 - Support Equipment Complexity F08 - Type of Failure Predominant F10 - On-Off Cycles per Sortie
Environmental Control System	F08 - Predominant Type of Failure
Electrical Power Generation	F13 - Removals to Access Other Equipment
Anti-Collision Lights	F03 - Equipment Weight F06 - Support Equipment Complex
Landing/Taxi Lights	F03 - Equipment Weight F13 - Removals to Access Other Equipment

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 16 SUBSYSTEM MAD AS A FUNCTION OF EQUIPMENT PARAMETERS ONLY
(Sheet 3)

SUBSYSTEM	EQUIPMENT PARAMETERS ENTERING MAD ESTIMATING EQUATION
Hydraulic Power System	F04 - Equipment Volume F11 - Ground/Flight Operating Ratio
Internal Fuel System	F16 - Equipment Protection Methodology
Oxygen Regulator	F03 - Equipment Weight
LOX Converter	F08 - Predominant Type of Failure
Engine Fire Detection	F04 - Equipment Volume F08 - Predominant Type of Failure

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 17 SUBSYSTEM MAD AS A FUNCTION OF OPERATIONAL PARAMETERS ONLY
(Sheet 1)

SUBSYSTEM	OPERATIONAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Propulsion System	Ø10 - Average Cruise Altitude Ø14 - Average Landing Weight Ø27 - Operations Sorties per Aircraft Ø32 - Aircraft Crew Size Ø33 - Average Sortie Length
Flight Indicators	Ø11 - Average Descent Rate Ø13 - Minimum Landing Distance Ø17 - Operations Flying Hours per Aircraft Ø25 - Total Sorties per Aircraft
Air Data System	Ø08 - Average Climb Rate Ø13 - Minimum Landing Distance Ø23 - Average Number of Alert Aircraft
Horizontal Situation Indicator	Ø14 - Average Landing Weight Ø33 - Average Sortie Length
Autopilot	Ø08 - Average Climb Rate Ø23 - Average Number of Alert Aircraft
UHF Communication Set	Ø08 - Average Climb Rate Ø18 - Miscellaneous Flying Hours per Aircraft
IFF Transponder Set	Ø05 - Average Take-Off Speed Ø09 - Average Cruise Speed Ø12 - Average Landing Speed Ø30 - Maximum Aircraft Speed
Inertial Navigation Set	Ø13 - Minimum Landing Distance
Instrument Landing Set	Ø15 - Total Flying Hours per Aircraft Ø27 - Operations Sorties per Aircraft Ø32 - Aircraft Crew Size
TACAN Set	Ø15 - Total Flying Hours per Aircraft Ø32 - Aircraft Crew Size
Attitude-Heading Reference Set	Ø05 - Average Take-Off Speed

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 17 SUBSYSTEM MAD AS A FUNCTION OF OPERATIONAL PARAMETERS ONLY
(Sheet 2)

SUBSYSTEM	OPERATIONAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Radar Set	Ø10 - Average Cruise Altitude Ø11 - Average Descent Rate
Radome	Ø05 - Average Take-Off Speed Ø12 - Average Landing Speed Ø21 - Operations Landings per Aircraft Ø25 - Total Sorties per Aircraft
Windshields	Ø15 - Total Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft
Wings	Ø02 - Years Aircraft Have Been On Base Ø08 - Average Climb Rate Ø10 - Average Cruise Altitude Ø12 - Average Landing Speed Ø14 - Average Landing Weight Ø17 - Operations Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft
Cockpit Furnishings	Ø08 - Average Climb Rate Ø12 - Average Landing Speed Ø17 - Operations Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø25 - Total Sorties per Aircraft Ø27 - Operations Sorties per Aircraft
Main Landing Gear	Ø10 - Average Cruise Altitude Ø14 - Average Landing Weight Ø15 - Total Flying Hours per Aircraft Ø16 - Training Flying Hours per Aircraft Ø19 - Total Landings per Aircraft Ø21 - Operations Landings per Aircraft Ø32 - Aircraft Crew Size
Brakes	Ø03 - Average Mission Mix Ø05 - Average Take-Off Speed Ø09 - Average Cruise Speed Ø16 - Training Flying Hours per Aircraft Ø20 - Training Landings per Aircraft Ø26 - Training Sorties per Aircraft Ø31 - Aircraft Service Ceiling

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 17 SUBSYSTEM MAD AS A FUNCTION OF OPERATIONAL PARAMETERS ONLY
(Sheet 3)

SUBSYSTEM	OPERATIONAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Stabilator	Ø15 - Total Flying Hours per Aircraft Ø27 - Operations Sorties per Aircraft
Rudder	Ø15 - Total Flying Hours per Aircraft Ø17 - Operations Flying Hours per Aircraft Ø34 - Accidents (Major/Minor) per Aircraft
Flaps	Ø15 - Total Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft
Environmental Control System	None (No Correlated Data)
Electrical Power Generation	ØØ7 - Average Take-Off Weight(% Max.Take-Off Weight) Ø32 - Aircraft Crew Size
Anti-Collision Lights	Ø11 - Average Descent Rate Ø21 - Operations Landings per Aircraft Ø25 - Total Sorties per Aircraft Ø27 - Operations Sorties per Aircraft
Landing/Taxi Lights	Ø15 - Total Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft
Hydraulic Power System	ØØ5 - Average Take-Off Speed ØØ6 - Median Take-Off Distance ØØ8 - Average Climb Rate Ø14 - Average Landing Weight Ø32 - Aircraft Crew Size Ø33 - Average Sortie Length
Internal Fuel System	Ø1Ø - Average Cruise Altitude Ø11 - Average Descent Rate Ø15 - Total Flying Hours per Aircraft Ø17 - Operations Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 17 SUBSYSTEM MAD AS A FUNCTION OF OPERATIONAL PARAMETERS ONLY
(Sheet 4)

SUBSYSTEM	OPERATIONAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Oxygen Regulator	Ø30 - Maximum Aircraft Speed
LOX Converter	Ø05 - Average Take-Off Speed Ø06 - Median Take-Off Distance Ø33 - Average Sortie Length
Engine Fire Detection	None (No Correlated Data)

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 18 SUBSYSTEM MAD AS A FUNCTION OF ENVIRONMENTAL PARAMETERS ONLY (Sheet 1)

SUBSYSTEM	ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Propulsion System	E13 - Number of Thunder Days per Year
Flight Indicators	E03 - Runway Direction E19 - Days per Year Max. Crosswinds 20-29 MPH
Air Data System	E13 - Number of Thunder Days per Year E19 - Days per Year Max. Crosswinds 20-29 MPH E20 - Days per Year Max. Crosswinds 30-39 MPH
Horizontal Situation Indicator	E13 - Number of Thunder Days per Year E18 - Days per Year Max. Crosswinds 10-19 MPH E20 - Days per Year Max. Crosswinds 30-39 MPH
Autopilot	E08 - Mean Snow Depth E18 - Days per Year Max. Crosswinds 10-19 MPH
UHF Communication Set	E13 - Number of Thunder Days per Year E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH E27 - Days per Year Min. Temp. Below 32° F E30 - Predominant Type of Vision Obstruction
IFF Transponder Set	E06 - Number of Snow Days per Year E09 - Number of Rain Days per Year E31 - Average Severity of Vision Obstruction
Inertial Navigation Set	E21 - Days per Year Max. Crosswinds 40-49 MPH
Instrument Landing Set	E20 - Days per Year Max. Crosswinds 30-39 MPH
TACAN Set	E03 - Runway Direction E09 - Number of Rain Days per Year E13 - Number of Thunder Days per Year E20 - Days per Year Max. Crosswinds 30-39 MPH
Attitude-Heading Reference Set	E27 - Days per Year Min. Temp. Below 32° F
Radar Set	E13 - Number of Thunder Days per Year E16 - Predominant Wind Direction E18 - Days per Year Max. Crosswinds 10-19 MPH E20 - Days per Year Max. Crosswinds 30-39 MPH

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 18 SUBSYSTEM MAD AS A FUNCTION OF ENVIRONMENTAL PARAMETERS ONLY (Sheet 2)

SUBSYSTEM	ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Radome	E02 - Base Altitude E18 - Days per Year Max. Crosswinds 10-19 MPH E20 - Days per Year Max. Crosswinds 30-39 MPH
Windshield	E18 - Days per Year Max. Crosswinds 10-19 MPH
Wings	E13 - Number of Thunder Days per Year E20 - Days per Year Max. Crosswinds 30-39 MPH
Cockpit Furnishings	E20 - Days per Year Max. Crosswinds 30-39 MPH
Main Landing Gear	E20 - Days per Year Max. Crosswinds 30-39 MPH
Brakes	E03 - Runway Direction E16 - Predominant Wind Direction
Stabilator	E20 - Days per Year Max. Crosswinds 30-39 MPH
Rudder	E03 - Runway Direction E09 - Number of Rain Days per Year E18 - Days per Year Max. Crosswinds 10-19 MPH E24 - Mean Minimum Temperature
Flaps	E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH
Environmental Control System	E19 - Days per Year Max. Crosswinds 20-29 MPH E24 - Mean Minimum Temperature
Electric Power Generation	E13 - Number of Thunder Days per Year
Anti-Collision Lights	E02 - Base Altitude E03 - Runway Direction E18 - Days per Year Max. Crosswinds 10-19 MPH E30 - Average Vision Obstruction Type
Landing/Taxi Lights	E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH
Hydraulic Power System	E06 - Number of Snow Days per Year E08 - Mean Snow Depth

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 18 SUBSYSTEM MAD AS A FUNCTION OF ENVIRONMENTAL PARAMETERS ONLY
(Sheet 3)

SUBSYSTEM	ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Internal Fuel System	E16 - Predominant Wind Direction E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH E23 - Mean Temperature
Oxygen Regulator	E06 - Number of Snow Days per Year E07 - Total Snow Fall E16 - Predominant Wind Direction E21 - Days per Year Max. Crosswinds 40-49 MPH E23 - Mean Temperature E24 - Mean Minimum Temperature E27 - Days per Year Minimum Temp. Below 32^{o} F
LOX Converter	E08 - Mean Snow Depth
Engine Fire Detection	E16 - Predominant Wind Direction E19 - Days per Year Max. Crosswinds 20-29 MPH E24 - Mean Minimum Temperature

NOTE: SEE APPENDIX D FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

subsystem's generic model in those respective categories. Summary listings of the thirty complete model equations in each generic category are included in Appendix D of this report. Complete details and listings of the generic models may be found in Boeing Interim Technical Report D194-10089-3 (Reference 17).

7.2 DEVELOPMENT OF COMPOSITE MAINTENANCE ACTION DEMAND ESTIMATING MODELS - SUBTASKS 6 & 7.4 and 6 & 7.5

The next step in the development of comprehensive Maintenance Metrics and Weightings Models for aircraft was the derivation of MAD estimating models which combine the maintenance impacts of equipment, operational, and environmental characteristics in a single model for each subsystem studied (refer to Figure 16). To this end, composite model development data sets were assembled for each aircraft subsystem. The equipment, operational, and environmental parameters selected for inclusion in each data set were those parameters which were included in the generic models for each subsystem.

The STAT PACK Stepwise Regression routine was then applied to each of these composite data sets to find the "best fit" MAD estimating multiple regression model from among the candidate independent variables (equipment, operational, and environmental parameters) included in the set corresponding to each aircraft subsystem studied. This effort resulted in the derivation of thirty composite Maintenance Metrics and Weightings Models for the estimation of maintenance action demand. The form of the models is as follows:

$$\begin{aligned} MAD = {} & A+(B_1\text{Equip Param}_1+\ldots+B_m\text{Equip Param}_m) + \\ & +(C_1\text{Opnl Param}_1+\ldots+C_n\text{Opnl Param}_n)+\ldots \\ & \ldots+(D_1\text{Environ Param}_1+\ldots+D_p\text{Environ Param}_p). \end{aligned}$$

Table 19 lists the specific equipment, operational, and environmental characteristic parameters which enter the "Composite" model for each subsystem. A summary list of these thirty complete model equations are included in Appendix E of this report. Complete details and listing of the composite models may be found in Boeing Interim Technical Report D194-10089-3 (Reference 17).

17 "Development of Maintenance Metrics to Forecast Resource Demands of Weapon Systems (Maintenance Metrics and Weightings," D194-10089-3, Boeing Aerospace Company, Seattle, Washington, January 1080.

TABLE 19 SUBSYSTEM MAD AS A COMPOSITE FUNCTION OF EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS
(Sheet 1)

SUBSYSTEM	EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Propulsion System	P02 - Total Number of Installed Engines per Aircraft P04 - Weight per Engine Ø10 - Average Cruise Altitude Ø27 - Operational Sorties per Aircraft Ø32 - Aircraft Crew Size Ø33 - Average Sortie Length
Flight Indicators	A03 - Equipment Weight Ø13 - Minimum Landing Distance Ø17 - Operations Flying Hours per Aircraft E03 - Runway Direction E19 - Days per Year Max. Crosswinds 20-29 MPH
Air Data System	A03 - Equipment Weight A16 - On/Off Cycles per Flying Hour Ø08 - Average Climb Rate Ø13 - Minimum Landing Distance Ø23 - Average Number of Alert Aircraft E13 - Number of Thunder Days per Year E19 - Days per Year Max. Crosswinds 20-29 MPH
Horizontal Situation Indicator	A07 - Cooling Method A16 - On/Off Cycles per Flying Hour Ø14 - Average Landing Weight Ø33 - Average Sortie Length E20 - Days per Year Max. Crosswinds 30-39 MPH
Autopilot	A03 - Equipment Weight A04 - Equipment Volume A13 - Average Operating Time per Sortie A19 - Failure/Abort Ratio Ø08 - Average Climb Rate Ø23 - Average Number of Alert Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH

NOTE: SEE APPENDIX E FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 19 SUBSYSTEM MAD AS A COMPOSITE FUNCTION OF EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS

(Sheet 2)

SUBSYSTEM	EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
UHF Communications Set	A03 - Equipment Weight A05 - Number of SRU's per Unit Ø08 - Average Climb Rate Ø18 - Miscellaneous Flying Hours per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH E30 - Average Type of Vision Obstruction
IFF Transponder Set	A02 - Equipment Location on Aircraft A09 - Number of Test Points on Unit Ø30 - Maximum Aircraft Speed E09 - Number of Rain Days per Year
Inertial Navigation Set	A05 - Number of SRU's per Unit
Instrument Landing Set	A06 - Operating Emperature Ø15 - Total Flying Hours per Aircraft Ø27 - Operations Sorties per Aircraft E20 - Days per Year Max. Crosswinds 30-39 MPH
TACAN Set	A03 - Equipment Weight A18 - Ground/Flight Operating Ratio Ø32 - Aircraft Crew Size E03 - Runway Direction E09 - Number of Rain Days per Year E20 - Days per Year Max. Crosswinds 30-39 MPH
Attitude-Heading Reference Set	A08 - Protective Method Ø05 - Average Take-Off Speed E27 - Days per Year Min. Temp. Below 32° F
Radar Set	A02 - Equipment Location on Aircraft A12 - AGE Unreliability A19 - Failure/Abort Ratio Ø11 - Average Descent Rate E13 - Number of Thunder Days per Year E20 - Days per Year Max. Crosswinds 30-39 MPH

NOTE: SEE APPENDIX E FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 19 SUBSYSTEM MAD AS A COMPOSITE FUNCTION OF EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS
(Sheet 3)

SUBSYSTEM	EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Radome	F08 - Type of Failure Problems Predominant Ø05 - Average Take-Off Speed Ø21 - Operations Landings per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH
Windshield	F07 - Support Equipment Reliability Ø15 - Total Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH
Wings	F04 - Equipment Volume Ø08 - Average Climb Rate Ø12 - Average Landing Speed Ø14 - Average Landing Weight Ø21 - Operations Landings per Aircraft E13 - Number of Thunder Days per Year E20 - Days per Year Max. Crosswinds 30-39 MPH
Cockpit Furnishings	Ø08 - Average Climb Rate Ø12 - Average Landing Speed Ø17 - Operations Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø25 - Total Sorties per Aircraft Ø27 - Operations Sorties per Aircraft E19 - Days per Year Max. Crosswinds 20-29 MPH
Main Landing Gear	F03 - Equipment Weight F06 - Support Equipment Complexity F13 - Removals to Access Other Equipment Ø14 - Average Landing Weight Ø19 - Total Landings per Aircraft
Brakes	F09 - Inflight Squawk Verfification Rate Ø03 - Average Mission Mix Ø05 - Average Take-Off Speed Ø26 - Training Sorties per Aircraft Ø31 - Service Aircraft Ceiling E03 - Runway Direction

NOTE: SEE APPENDIX E FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 19 SUBSYSTEM MAD AS A COMPOSITE FUNCTION OF EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS
(Sheet 4)

SUBSYSTEM	EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Stabilator	F03 - Equipment Weight F06 - Support Equipment Complexity Ø21 - Operations Landings per Aircraft E20 - Days per Year Max. Crosswinds 30-39 MPH
Rudder	Ø15 - Total Flying Hours per Aircraft Ø34 - Accidents (Major/Minor) per Aircraft E03 - Runway Direction
Flaps	F03 - Equipment Weight F06 - Support Equipment Complexity F08 - Predominant Type of Failure Problems Ø15 - Total Flying Hours per Aircraft Ø27 - Operations Sorties per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH
Environmental Control System	E19 - Days per Year Max. Crosswinds 20-29 MPH E24 - Mean Minimum Temperature
Electric Power Generation	F13 - Removals to Access Other Equipment Ø07 - Average Take-Off Weight as % of Maximum
Anti-Collision Lights	F03 - Equipment Weight F06 - Support Equipment Complexity Ø11 - Average Descent Weight Ø21 - Operations Landings per Aircraft Ø25 - Total Sorties per Aircraft Ø27 - Operations Sorties per Aircraft E30 - Average Type of Vision Obstruction
Landing/Taxi Lights	F03 - Equipment Weight F13 - Removals to Access Other Equipment Ø15 - Total Flying Hours per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH

NOTE: SEE APPENDIX E FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

TABLE 19 SUBSYSTEM MAD AS A COMPOSITE FUNCTION OF EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS
(Sheet 5)

SUBSYSTEM	EQUIPMENT, OPERATIONAL, AND ENVIRONMENTAL PARAMETERS ENTERING MAD ESTIMATION EQUATION
Hydraulic Power System	F11 - Ground/Flight Operating Ratio Ø08 - Average Climb Rate Ø14 - Average Landing Weight Ø32 - Aircraft Crew Size Ø33 - Average Sortie Length E06 - Number of Snow Days per Year E08 - Mean Snow Depth
Internal Fuel System	F16 - Equipment Protection Methodology Ø10 - Average Cruise Altitude Ø15 - Total Flying Hours per Aircraft Ø21 - Operations Landings per Aircraft Ø27 - Operations Sorties per Aircraft E18 - Days per Year Max. Crosswinds 10-19 MPH E19 - Days per Year Max. Crosswinds 20-29 MPH
Oxygen Regulator	F03 - Equipment Weight Ø30 - Maximum Aircraft Speed E06 - Number of Snow Days per Year E07 - Total Snow Fall per Year E21 - Days per Year Max. Crosswinds 40-49 MPH E24 - Mean Minimum Temperature E27 - Days per Year Min. Temp. Below 32° F
LOX Converter	F08 - Predominant Type of Failure Problems Ø05 - Average Take-Off Speed Ø06 - Median Take-Off Distance Ø33 - Average Sortie Length
Engine Fire Detection	F08 - Predominant Type of Failure Problems E16 - Predominant Wind Direction E19 - Days per Year Max. Crosswinds 20-29 MPH E24 - Mean Minimum Temperature

NOTE: SEE APPENDIX E FOR A LISTING OF COMPLETE MAD ESTIMATING EQUATIONS.

7.3 DEVELOPMENT OF LCOM FAILURE CLOCK CALCULATION ROUTINE - SUBTASK 6 & 7.6

The maintenance action demand estimations obtained from the Maintenance Metrics and Weightings Models discussed in 7.1 and 7.2 are in terms of maintenance actions per unit equipment per year. One of the principle requirements of Tasks VI and VII is to translate these estimations into Failure Clock values for control of LCOM subsystem maintenance networks. Since these F-clock values are usually some derivative of "number of sorties to maintenance action," a computational routine for accomplishing this translation is required. Figure 17 is a process flow depicting this routine. The detailed procedure for accomplishing the F-clock transformation follows.

PROCEDURE FOR TRANSFORMING PRESENT LCOM FAILURE CLOCK VALUES TO CONFORM WITH MAINTENANCE METRICS MODEL ESTIMATES

(1) Determine actual historical time period used to derive present LCOM values.

(2) Determine actual maintenance action demand (AMAD) of subsystem of interest during that time period. Determine partial maintenance action demand (PAMAD) of subsystem critical equipment used to derive maintenance metrics model equation.

(3) Determine appropriate "operating point"[1] values for item's Metrics Model regression variables. These values may either be derived from historic design and scenario data or from new simulated design and scenario data as appropriate depending on the nature of the simulation experiments to be performed.

(4) Compute partial estimated maintenance action demand (PEMAD) for the same historic time period using Maintenance Metrics Regression Model. Scale this result up to total subsystem estimated maintenance demand (EMAD) by multiplying by the AMAD/PAMAD ratio.

(5) Compute ratio of EMAD to AMAD.

NOTE:

1 - Operating point is defined here as the system of design, operational support, and environmental conditions applicable to the item-of-interest. This may be some actual historic operating point featuring retrospective data, a predicted operating point featuring prospective estimates, or it may be a mixture of the two.

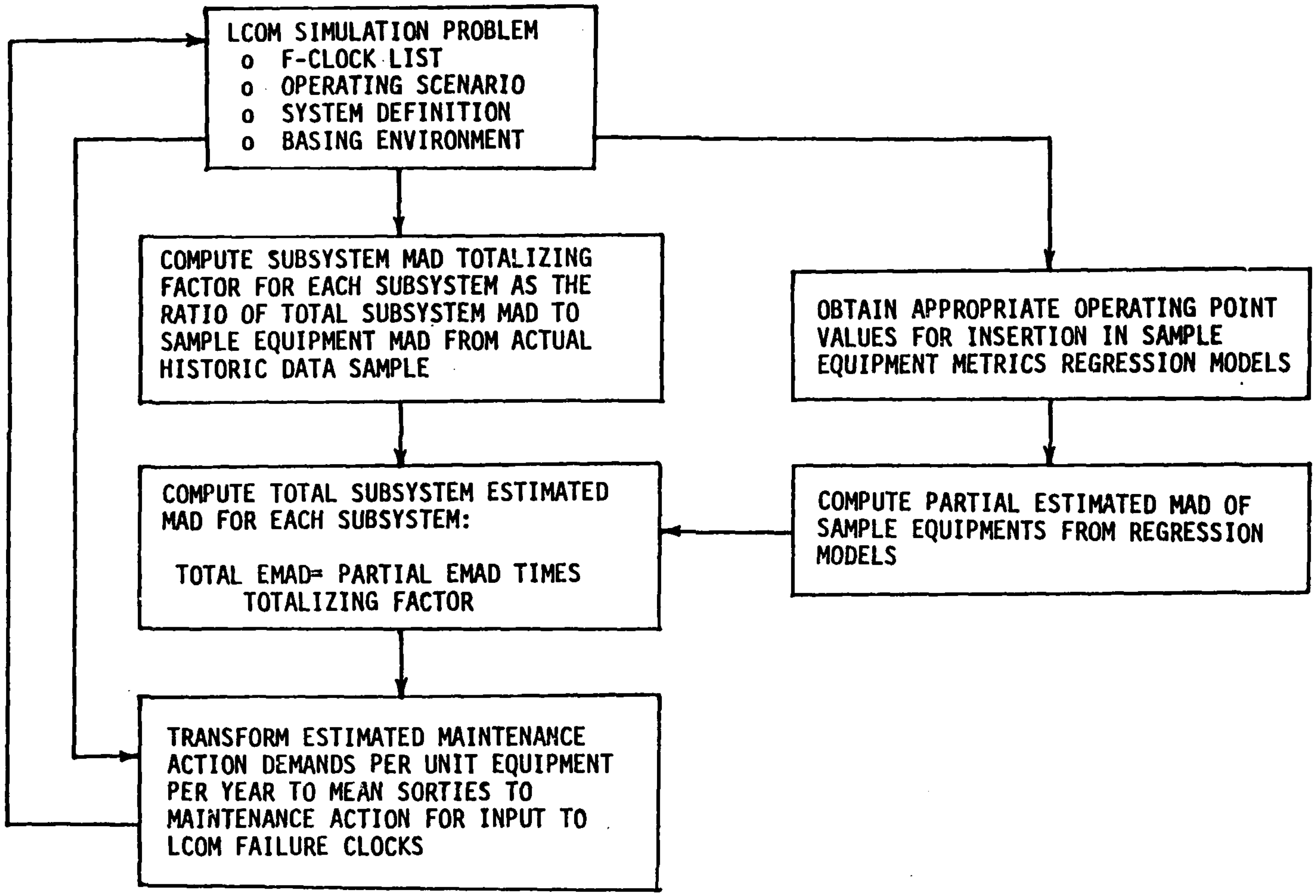

FIGURE 17 LCOM FAILURE CLOCK COMPUTATION PROCESS FLOW

(6) Multiply present clock values (or decrement value if appropriate) by the EMAD/AMAD ratio[2] to transform clock value to the maintenance Metric based estimate.

(7) If new clock value is to be substituted into an existing LCOM input model and it is desired not to disturb the existing input data base, add a clock change card to the LCOM simulation control deck designating the appropriate clock number and new clock value.

The requirement for and explanation of this rather complicated procedure is as follows:

The generic and composite Maintenance Metrics and Weightings regression equations developed for the study were based on a sampling of the critical equipment items in each aircraft subsystem. Critical equipments are considered to be those items (usually only one or two) within a subsystem which drive the maintenance resource demands of that subsystem and may be used to represent the total subsystem without serious degradation of maintenance metrics analysis results. Critical equipments rather than total subsystems were used for maintenance metrics development because the far greater time and resources required for the data gathering and analysis of each item in each subsystem could not be justified in terms of the increased accuracy of the metrics developed (Refer to Sections 3 and 5 of this report for discussions of subsystem equipment selection and data acquisition). Therefore, as shown in Figure 17 and the procedure, transforming the outputs of the regression models to F-clock values provides for scaling the partial MAD estimates based on the selected equipment items up to total subsystem MAD estimates for LCOM network control, since the LCOM maintenance networks are structured at the subsystem level and the F-clock values are based on total subsystem demands. This is accomplished through the utilization of an actual sample of historical maintenance action demand data for the subsystems (or similar subsystems if new equipment) being analyzed and simulated. This actual data is used to calculate a ratio factor of total subsystem MAD to selected equipment sample MAD. This total subsystem MAD scale factor can then be applied to the partial MAD estimates

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NOTE:

2 - The Maintenance Metrics Models are of greatest value when performing prospective simulation and analyses on new systems and/or new scenarios. Under these conditions it is postulated that they will provide better results than simplistic projections of historic failures per sortie or per flying hour. If, however, an exact historical scenario is being simulated (a retrospective analysis of what actually happened), the historical data should provide better results than the "fitted" Maintenance Metrics estimates.

computed from the regression models of the new aircraft and/or basing situation being simulated to yield total subsystem MAD estimates for translation into F-clock values at the LCOM maintenance network level. The last step in the translation process is to obtain an estimate of sorties per year to be accomplished (usually obtained from the simulation scenario) and to calculate the sorties-to-failure values corresponding to each subsystem MAD per year. A sample of the calculation work sheet to be used for the F-clock computation routine and a typical example of the application of this procedure to the F-15A/Bitburg baseline LCOM are included in Appendix F of this report.

7.4 DEVELOPMENT OF MAINTENANCE TASK PROBABILITY ESTIMATING MODELS - SUBTASK 6 & 7.8

The last subtask to be accomplished within the Task VI and VII effort was the development of an estimating method for the maintenance task selection probabilities necessary for the control of the LCOM maintenance networks. The process flow for this subtask was as depicted by Figure 18 and as shown, task frequency data was extracted from the data base collected in study task IV (see Section 5.0). This data was extracted at both the subsystem and included equipment levels for each data case of the study (aircraft/base combination) for each of the thirty aircraft subsystems studied. The data was then utilized to compute weighted average maintenance task selection probabilities for each subsystem/aircraft/base combination. The weighting factors were based on the ratio of frequency of maintenance of each equipment item within a given subsystem to the frequency of maintenance of the subsystem as a whole. It is necessary to weight the task frequencies of the component equipments because the equipment items within a subsystem do not fail with equal frequency and therefore the task distributions on the various subsystem components must be weighted according to each's proportion of total subsystem failures.

The weighted average task selection probabilities discussed above were then assembled in summary data sets by subsystem and the mean, median, mode and range of the probability of occurrence of each task type computed for each aircraft subsystem. These resulting statistics can now be used to estimate the expected task selection probability distributions required for control of the various subsystem maintenance networks in LCOM simulation problems. Figure 19 is an overview of the foregoing analysis process. Table 20 presents a summary of the resulting mean task selection probability distributions for the various subsystems. Complete details, data and statistics used to develop the task selection probabilities may be found in Boeing Interim Technical Report D194-10089-3 (Reference 17).

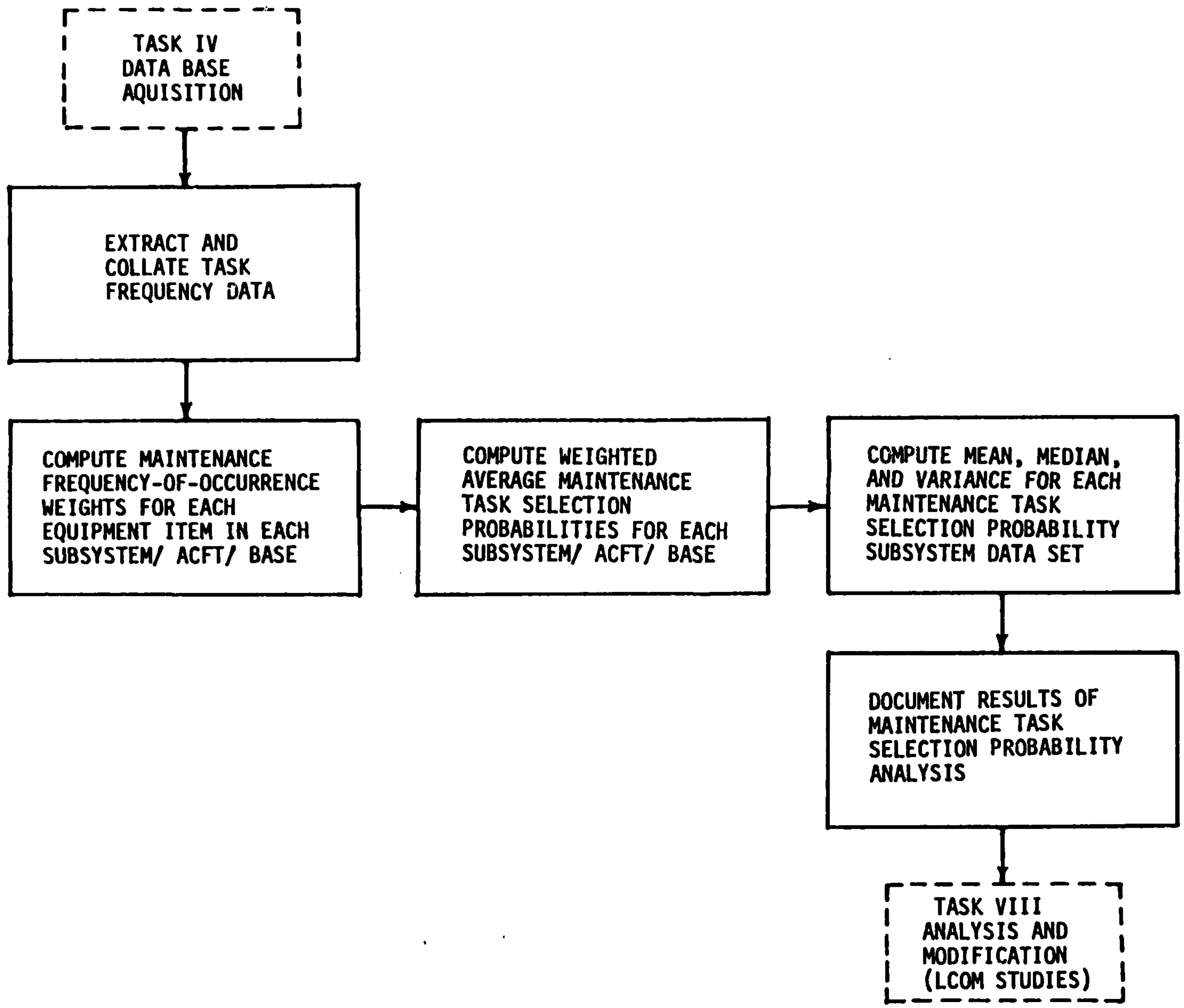

FIGURE 18 MAINTENANCE TASK SELECTION PROBABILITY PROCESS FLOW

- DEVELOP MEAN PROBABILITY PREDICTIONS FOR LCOM MAINTENANCE NETWORK TASK ALTERNATIVES

<u>ON EQUIP TASK ALTERNATIVES</u>

- (H) CHECK OK PROBABILITY
- (M) FIX IN PLACE PROBABILITY
- (R) REMOVE/REPLACE PROBABILITY

<u>OFF EQUIP TASK ALTERNATIVES</u>

- (N) NOT REPAIRABLE PROBABILITY
- (K) BENCH CHECK OK PROBABILITY
- (W) FIX IN SHOP PROBABILITY

- FOR EACH AIRCRAFT SUBSYSTEM LCOM NETWORK - -
  - COMPUTE WEIGHTED AVERAGE TASK PROBABILITIES BASED ON HISTORICAL MAINTENANCE TASK DATA WEIGHTED BY SUBSYSTEM COMPONENT RELATIVE FAILURE FREQUENCY DATA.
  - COMPUTE MEAN, MEDIAN, AND RANGE OF WEIGHTED AVERAGE TASK PROBABILITIES ACROSS ALL AIRCRAFT/BASE COMBINATIONS STUDIED.
- USE MEAN TASK PROBABILITY ANALYSIS RESULTS TO PREDICT EXPECTED MAINTENANCE TASK SELECTION PROBABILITIES FOR NEW SYSTEMS.

FIGURE 19 MAINTENANCE TASK SELECTION PROBABILITY ANALYSIS OVERVIEW

TABLE 20 SUMMARY OF MEAN TASK SELECTION PROBABILITY DISTRIBUTIONS

AIRCRAFT EQUIPMENT SUBSYSTEM	ON EQUIPMENT MEAN TASK PROBABILITY DISTRIBUTION			OFF EQUIPMENT MEAN TASK PROBABILITY DISTRIBUTION		
	R REMOVE	M FIX	H CHK OK	N SENT ON	K CHK OK	W FIX
23000 Propulsion	0.339	0.536	0.125	0.388	0.138	0.474
51A00 Flight Indicators	0.571	0.343	0.086	0.768	0.146	0.086
51E00 Air Data System	0.414	0.436	0.150	0.509	0.205	0.286
51N00 Horizontal Situation Indic.	0.586	0.226	0.188	0.699	0.149	0.152
52A00 Autopilot	0.573	0.208	0.219	0.354	0.246	0.400
63A00 UHF Communication Set	0.529	0.343	0.128	0.168	0.120	0.712
65A00 IFF Transponder Set	0.540	0.219	0.241	0.105	0.232	0.663
71A00 Inertial Navigation Set	0.390	0.119	0.491	0.343	0.171	0.486
71C00 Instrument Landing Set	0.421	0.310	0.269	0.069	0.158	0.773
71D00 TACAN Set	0.650	0.174	0.176	0.182	0.200	0.618
71F00 Attitude-Heading Ref. Set	0.650	0.157	0.193	0.661	0.193	0.146
74F00 Radar Set	0.496	0.183	0.321	0.220	0.113	0.667
11A01 Radome Assembly	0.147	0.837	0.016	0.067	0	0.933
11A02 Windshield	0.142	0.820	0.038	0.124	0	0.876
11K00 Wings	0.128	0.859	0.013	0.056	0.038	0.906
12B00 Cockpit Furnishings	0.154	0.775	0.071	0.450	0.009	0.541
13A00 Main Landing Gear	0.713	0.014	0.273	0.317	0.548	0.135
13D00 Brake Subsystem	0.373	0.424	0.203	0.425	0.188	0.387
14C00 Stabilator Subsystem	0.163	0.716	0.121	0.424	0.116	0.460
14D00 Rudder Subsystem	0.201	0.534	0.265	0.307	0.159	0.534
14H00 Flap Subsystem	0.154	0.620	0.226	0.412	0.013	0.575
41A00 Environmental Control System	0.499	0.408	0.093	0.404	0.062	0.534
42A00 Electric Power Gen. System	0.391	0.569	0.040	0.445	0.193	0.362
44A01 Navigation Lights	0.440	0.549	0.011	0.174	0.028	0.798
44A02 Landing/Taxi Lights	0.365	0.628	0.007	0.285	0.027	0.688
45A00 Hydraulic Power System	0.257	0.599	0.144	0.532	0.252	0.216
46A00 Internal Fuel Subsystem	0.187	0.661	0.152	0.683	0.050	0.267
47A01 Oxygen Regulator	0.656	0.258	0.086	0.923	0.024	0.053
47A0a LOX Converter	0.545	0.372	0.083	0.772	0.145	0.083
49A00 Fire Detection System	0.338	0.606	0.056	0.550	0.182	0.268

8.0 ANALYSIS AND RESULTS OF METRICS AND WEIGHTINGS - TASK VIII

Task VIII of the study was the planning, execution, and analysis of validation experiments for the new maintenance metrics and weightings developed during the preceding study tasks. These experiments were performed on operative LCOM simulations of operational aircraft systems. The validation experiments were intended to demonstrate the validity of the new metrics and to indicate an approximate confidence level for their use.

The subtasks accomplished for these validation experiments are as shown in Figure 20 and discussed in the following paragraphs.

The approach taken for the validation of the maintenance metrics developed during the preceding study tasks was to exercise the newly developed metrics in known historical situation simulations and subsequently evaluate the success of these new metrics in producing similar simulation results as the actual historical data. The ability of the new maintenance metrics to duplicate the results of actual historical data is a measure of the worth of these metrics in predicting maintenance resource demands for emerging weapon systems under new operational and environmental conditions.

The metrics validation was planned and performed in two parts. First a series of LCOM simulation experiments was accomplished using a model of an aircraft/base combination (the F-15A at Bitburg Air Base) which was part of the study data base from which the maintenance metric equations were developed. A second series of LCOM experiments was then performed which used a model and aircraft/base combinations which were not part of the original metrics study data base. The model used for this second validation effort was the standard ASD KC-135A LCOM. The input data module for this model was developed from five KC-135A base samples not considered in the metrics study; i.e., Altus, Blytheville, Grand Forks, Griffiss, and K. I. Sawyer. Then, to decouple this second experiment series even further from the original metrics study data base, the bases chosen for simulation were neither part of the metrics study data base nor of the ASD standard data base; i.e., Loring, Seymour-Johnson, and Castle. This was done to test the performance of the new metrics in situations which were clearly outside the statistical data used for their derivation.

The initial validation experiments were performed using the ASD/McDonnell Douglas LCOM simulation of the F-15A aircraft at Bitburg Air Base as the baseline model. This model was first executed with the standard failure clocks which were derived from the historical data base on F-15A/Bitburg. Then a series of experimental simulation runs were executed using the maintenance metrics and weightings developed during this study to set the model's failure clocks. The results of the experimental simulations were then compared with the standard simulations in order to evaluate the worth of the newly developed maintenance metrics for the estimation of aircraft systems maintenance resource demands.

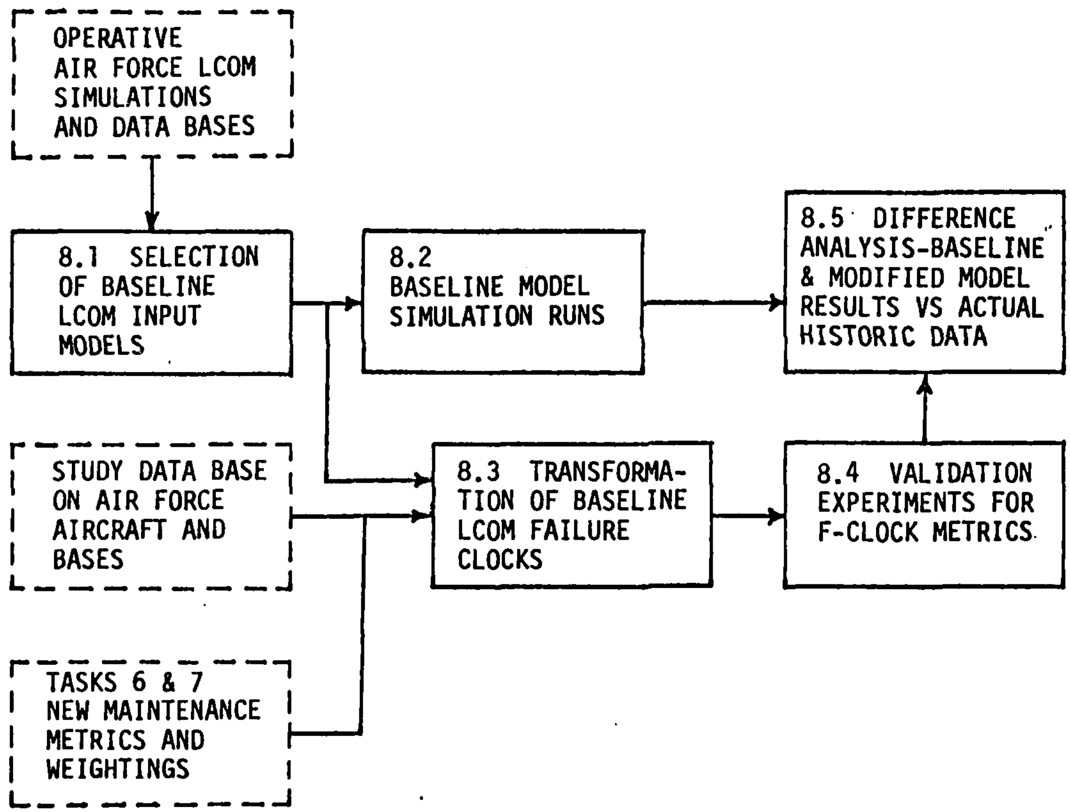

FIGURE 20 TASK VIII PROCESS FLOW

In the initial series of experimental model runs, maintenance metrics for the aircraft propulsion system and eleven avionic systems were exercised. The results of this initial series indicated that the avionics metrics were acceptable for use in predicting new situations with only approximately 10% deviation from the simulation results given by the actual historical data. The propulsion system metric indicated a need for further investigation and possible refinement since its introduction into the baseline simulation model caused wide variations from the actual historical propulsion data.

A more extensive series of validation experiments was then performed which exercised the developed metrics for all thirty aircraft subsystems investigated. A standard ASD LCOM simulation of the KC-135A aircraft was used to simulate three different bases with varying environments and operational modes, i.e.; Loring AFB, Maine, a two squadron operational base; Seymour-Johnson AFB, North Carolina, a single squadron operational base; and Castle AFB, California, a two squadron training base. These squadrons were first simulated using the ASD developed standard metrics with base-specific flying programs. Then the simulations were repeated using the newly developed maintenance metrics from this study. Finally, metrics derived from actual base-specific historical data were inserted and the simulations run again to form a basis for comparison. Output flying and maintenance parameters from the three sets of simulations of each base were compared for deviations. The simulation results from the base-specific historical metrics were taken as baselines. These baseline simulation results were in turn compared to actual flying and maintenance histories at the subject bases as extracted from the Air Force G033B and D056E data systems.

The results of this second series of metrics validation experiments exhibited quite low deviations. The simulations based on metrics values differed less than 3% for Loring and Castle AFB's and less than 9% for Seymour-Johnson AFB from the simulations based on historic base values. The overall fidelity of the KC-135A LCOM was also good. The deviation of the Loring baseline simulation results was less than 8% from actual historic flying and maintenance records while the corresponding deviations for Seymour-Johnson and Castle were less than 10% and less than 15% respectively. These results present solid evidence of the acceptability of the new maintenance metrics for use in predicting maintenance requirements in new situations.

Complete details and data pertaining to the Task VIII study effort are contained in Boeing Interim Technical Report D194-10089-4 (Reference 18) and are summarized in the remainder of Section 8.

8.1 SELECTION OF BASELINE LCOM INPUT MODEL - SUBTASK 8.1

The first step in the process of analyzing the results of metrics and weightings development effort of the preceding study tasks was the selection of operative LCOM simulations in which to test the newly developed metrics. Existing Air Force LCOM simulations were investigated and the ASD/McDonnell Douglas model of the F-15A aircraft at Bitburg Air Base selected for the initial series of metrics validation experiments. The model selected for subsequent series of experiments was the standard ASD model of the KC-135A aircraft.

Input models and flying programs for the selected models were implemented on the ITEL computer system in the ASD Computer Center at Wright-Patterson Air Force Base, Dayton, Ohio. The model data were based on 1977 experience data the same as the present study.

8.2 BASELINE MODEL SIMULATION RUNS USING CURRENT METRICS AND WEIGHTINGS - SUBTASK 8.2

After implementation of the baseline models on the ASD computing system, simulation runs were executed using the failure clock values currently operational in the input data bases for the models. These runs served to calibrate the natural variability of the baseline simulations and to establish a basis for comparison of the results of the later validation experiments which utilized the newly developed F-clock metrics. In addition, base-specific baselines were established for the KC-135A/Loring, Seymour-Johnson, and Castle AFB simulation series.

8.3 TRANSFORMATION OF BASELINE LCOM FAILURE CLOCKS - SUBTASK 8.3

The next step of the validation process was to implement the procedure for transforming the baseline failure clock values in the test models to values computed from the F-clock estimation equations developed in preceding study tasks VI and VII (see Section 7). The procedure developed utilized the "change-card" capability of the LCOM control software so as to facilitate ease of testing various combinations of modified clock values without disturbance to the basic baseline Input Data Model. This procedure has been described in detail in subsection 7.3 and Appendix F of this report.

Initially, the procedure was applied to the propulsion and eleven of the avionics failure clocks of the F-15A/Bitburg baseline model. The resulting F-clock values and their implications for the baseline F-15A/Bitburg LCOM are summarized in Table 21. Baseline values for the subject F-clocks had been calculated from 1977 Bitburg data prior to the model's use in the metrics study. The values for the regression variables were obtained from the F-15A/Bitburg entries in the Maintenance Metrics study data base. These transformed F-clocks were used according to the validation experiment plan presented in following subsection 8.4.

TABLE 21

APPLICATION OF METRIC MODELS TO F-15A (BITBURG) LCOM FAILURE CLOCKS (PHASE I EQUIPMENTS)

EQUIPMENT SUBSYSTEM (F15A)	F-15A LCOM F-CLOCK	BASELINE MODEL CLOCK VALUE	METRICS MODEL ADJUSTED CLOCK	DIFFERENCE	PERCENT DIFFERENCE FROM BASELINE	IMPLICATION FOR LCOM
PROPULSION - ENGINE #1	F23000	12	7	- 5	- 41.67	SIGNIFICANTLY HIGHER FAILURE RATE
ENGINE #2	F27000	12	7	- 5	- 41.67	
FLIGHT INDICATORS	F51A00	126	80	- 46	- 36.51	SIGNIFICANTLY HIGHER FAILURE RATE
AIR DATA SUBSYSTEM	F51E00	145	157	+ 12	+ 8.28	INSIGNIFICANT DIFFERENCE
HORIZ SITUATION INDICA.	F51N00	145	142	- 3	- 2.07	INSIGNIFICANT DIFFERENCE
AUTOPILOT	F52A00	91	86	- 5	- 5.49	INSIGNIFICANT DIFFERENCE
UHF COMMUNICATION SET	F63A00	32	62	+ 30	+ 93.75	MUCH LOWER FAILURE RATE
IFF TRANSPONDER SET	F65A00	18	17	- 1	- 5.56	INSIGNIFICANT DIFFERENCE
INERTIAL NAV. SET	F71A00	26	18	- 8	- 30.77	SIGNIFICANTLY HIGHER FAILURE RATE
INSTRU. LANDING SET	F71C00	108	*	- - -	- - -	- - -
TACAN SET	F71D00	83	88	+ 5	+ 6.02	INSIGNIFICANT DIFFERENCE
ATTIT.-HEADING REF. SET	F71F00	117	157	+ 40	+ 34.19	SIGNIFICANTLY LOWER FAILURE RATE
RADAR SET	F74F00	9	9	0	0	NO DIFFERENCE
			AVERAGE DIFFERENCE	+ 1.17	- 1.79	

*OPERATING POINT FROM BITBURG IN INDETERMINATE REGION OF ESTIMATING MODEL.

The F-clock transformation procedure was then applied to all 30 aircraft subsystems studied for the LCOM simulations of the three selected KC-135A bases. The simulation model used for these experiments contained generic ASD standard F-clock values derived from a composite of five representative KC-135A bases; i.e., Altus, Blytheville, Grand Forks, Griffiss, and K. I. Sawyer. Therefore it was necessary to calculate sets of base-specific baseline F-clock values for the three study bases; Loring, Seymour-Johnson, and Castle. Sortie and failure data from the year 1977 were used for this purpose. The D056E, G033B, and KC-135A source data used for calculation of the baseline failure clocks and also for use in the F-clock transformation regression equations is included in Reference 18. These baseline F-clock values were then imposed on the existing generic ASD KC-135A model via appropriate clock change cards for the base-specific baseline simulation runs.

The thirty study equipment failure clocks were then transformed to the maintenance metrics values for the metrics validation experiments. The values for the regression variables were obtained from the subject base entries in the 1977 G033B, D056E, and Air Weather Service data for maintenance demand, operations, and environmental variables. KC-135A equipment design characteristic data were obtained from the Maintenance Metrics study data base. Table 22 contains a summary of the ASD standard, baseline, and metrics derived F-clock values for each of the study bases. The validation experiment plan based on these transformed F-clock values is given in subsection 8.4.

8.4 NEW METRICS AND WEIGHTINGS VALIDATION EXPERIMENTS - SUBTASK 8.4

Series of simulation experiments were planned and executed with the F-15A and KC-135A models to demonstrate the validity of the new metrics. Figure 21 depicts the general procedure followed in the execution of these validation plans.

An initial series of LCOM simulation experiments was performed to evaluate the F-clock estimation equations for propulsion and avionics and their implications for F-15A/Bitburg model. Figure 22 gives the simulation plan for this series.

The objective of these experiments was to determine how well the generalized F-clock estimating models, which were derived from an Air Force-wide population of aircraft and bases, could duplicate simulation results based on actual historical failures per sortie data from a specific aircraft (F-15A), a specific base (Bitburg), and a specific time period (1977). This determination is a measure of the confidence that can be placed in the estimating equations when used in a new situation or for an emerging weapon system. The determination was made by exercising the F-15A/Bitburg LCOM simulation with the new F-clock values singly and in combination. The results of these simulations were then compared to baseline model runs as discussed in following subsection 8.5.

TABLE 22 SUMMARY OF F-CLOCK VALUES TRANSFORMED FOR KC-135A LCOM METRICS VALIDATION EXPERIMENTS

SYSTEM	F-CLOCK NUMBER I.D.	F-CLOCKS IN ASD KC-135A MODEL	F-CLOCKS LORING BASELINE	F-CLOCKS LORING METRICS	F-CLOCKS SEYMOUR-J BASELINE	F-CLOCKS SEYMOUR-J METRICS	F-CLOCKS CASTLE BASELINE	F-CLOCKS CASTLE METRICS
Propulsion	FA23AS	25.0	38.5	37.7	29.0	51.7	28.4	47.4
	FA23AO	567.0	789.5	773.7	782.0	1395.3	608.6	1016.4
	FA23BS	9.0	29.8	29.2	6.3	11.2	8.1	13.5
	FA23CS	103.0	17.5	17.2	11.7	20.9	18.6	31.1
	FA23DS	174.0	42.7	41.8	60.2	107.4	52.5	87.7
	FA23ES	10.4	32.2	31.6	10.4	18.6	9.2	15.4
	FA23HS	15.0	10.4	10.2	4.6	8.2	7.9	13.2
	FA23JS	9.0	5.1	5.0	2.7	4.8	4.7	7.8
	FA23JO	1134.0	789.5	773.7	391.0	697.6	608.6	1016.4
	FA23KS	4.0	6.1	6.0	3.7	6.2	6.1	10.2
	FA23LS	19.0	7.4	7.3	7.2	12.8	9.4	15.7
	FA23MS	7.0	6.4	6.3	5.2	9.3	3.7	6.2
	FA23NS	16.0	11.0	10.8	35.5	63.3	11.3	18.9
	FA23OS	39.0	225.6	221.1	10.6	18.9	50.7	84.7
	FA23PS	5.0	4.9	4.8	3.9	7.0	5.2	8.7
	FA23RS	13.0	8.3	8.1	5.7	10.2	7.0	11.7
	FA23RO	73.0	49.3	48.3	34.0	60.7	42.3	70.6
Flt. Indic.	FA511S	7.8	11.0	22.0	7.6	12.2	7.6	2.6
Air Data	FA518S	19.0	20.5	6.8	12.6	14.5	13.8	53.7
Horiz. Situa.	FA51AS	4.5	7.5	4.5	6.3	25.7	4.1	6.6
Autopilot	FA521S	18.0	27.2	20.1	41.2	19.6	26.2	43.0
	FA5210	5.8	9.1	6.7	13.5	6.4	8.8	14.4
UHF Comm.	FA63RS	87.0	4.4	41.0	7.7	51.3	7.8	12.5
IFF Set	FA65BS	10.6	17.2	30.4	11.3	28.6	15.3	86.8
Inst. Lndg.	FA71BS	13.6	21.6	9.7	41.2	25.7	27.4	14.5
Tacan	FA71CS	5.7	7.4	16.6	6.0	39.5	10.3	3.3
Radar	FA72BS	1.8	2.3	2.5	2.2	1.5	2.9	9.7
Fuselage	FA111S	450.0	4.2	0.9	6.7	9.8	7.3	3.1
Wings	FA11AO	18.0	21.1	15.6	17.0	49.5	18.8	16.2
	FA11JO	7.0	7.7	5.7	3.1	9.0	8.9	7.7
	FA11KO	7.3	8.0	5.9	2.8	8.2	11.9	10.2
	FA116S	99.0	131.6	97.4	130.3	379.7	86.9	74.7
	FA1160	44.0	65.8	48.7	71.1	207.2	43.5	37.4
	FA117S	103.0	121.5	89.9	156.4	455.8	144.9	124.6
	FA1170	37.0	41.6	30.8	55.9	162.9	48.3	41.5
Cockpit Furnishings	FA12AS	67.0	83.1	75.6	71.1	201.4	138.3	120.0
	FA12AO	142.0	157.9	143.7	156.4	443.1	276.6	240.0
Lndg. Gear	FA13AO	8.5	3.0	1.9	3.3	3.0	2.5	4.3
Brakes	FA13CS	3.0	4.7	22.4	10.7	16.8	5.4	36.9
Stabilator	FA11GO	27.0	23.6	17.0	60.2	14.0	53.4	19.2
Rudder	FA14BO	69.0	8.9	9.6	24.4	3.7	14.2	5.3
Flaps	FA14EO	11.0	3.0	2.2	4.8	5.0	6.0	15.7
Environ. Control	FA412S	18.6	38.5	55.0	32.6	186.0	31.1	44.4
	FA4120	26.0	56.4	80.7	48.9	279.2	46.1	65.9
Elect. Pwr.	FA421S	38.0	4.4	12.8	2.8	10.8	4.2	12.9
Hydr. Pwr.	FA451S	3.0	3.2	4.5	5.6	6.0	3.7	19.0
Internal Fuel	FA461S	12.0	12.0	49.1	31.3	55.2	14.6	833.1
	FA4620	13.0	10.7	43.8	39.1	68.9	12.7	724.6
	FA4630	23.0	22.6	92.5	71.1	125.3	17.6	1004.2
Lox Syst.	FA471S	10.0	13.4	24.9	11.3	45.8	14.4	50.9
Fire Detect.	FA494S	16.3	12.7	187.6	11.3	450.9	7.3	757.4

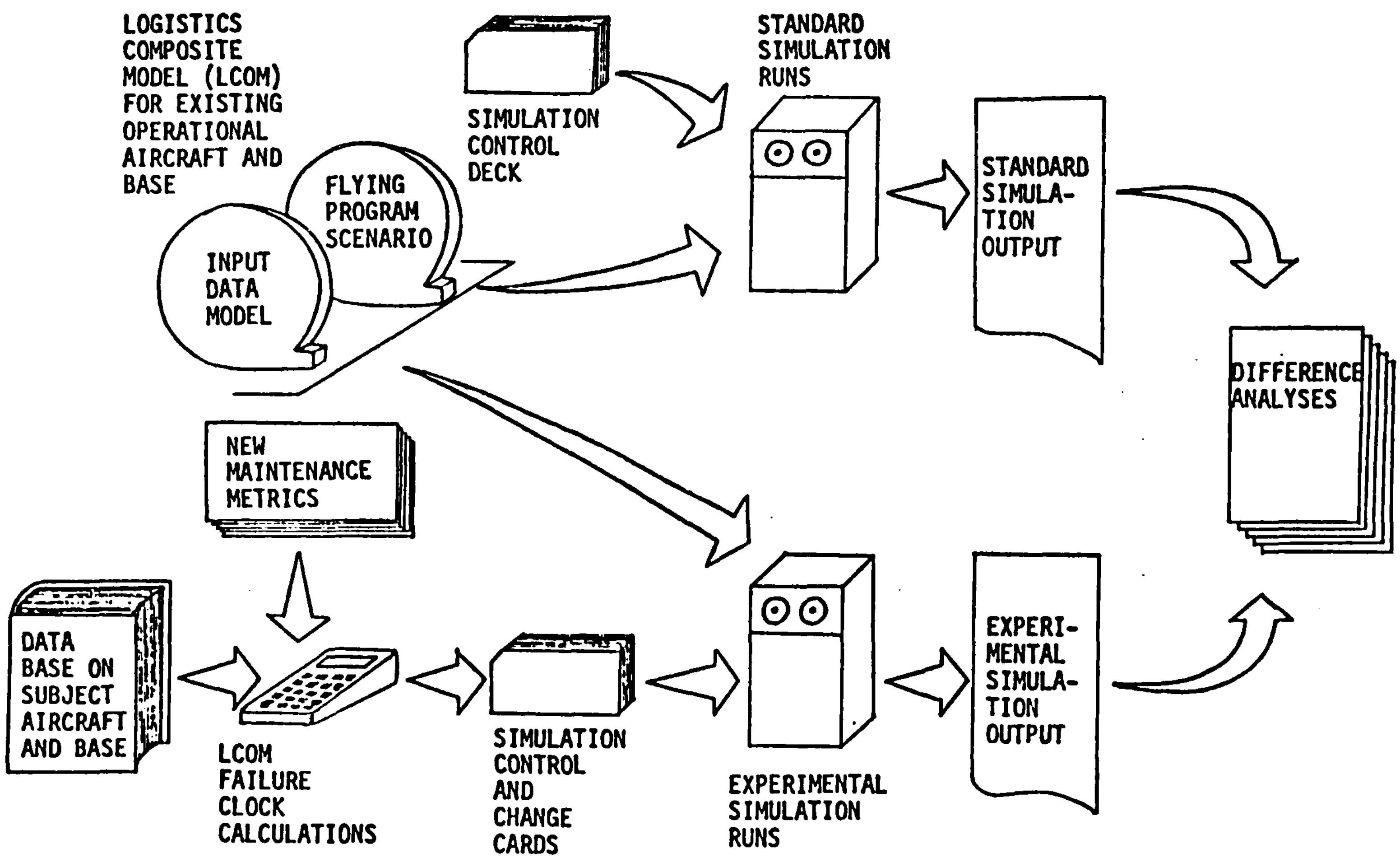

FIGURE 21 MAINTENANCE METRICS VALIDATION EXPERIMENT PROCEDURE

INITIAL SERIES--ASD/MCDONNELL DOUGLAS LCOM SIMULATION OF F-15A/BITBURG (1977 DATA BASE)

- SERIES 1 BASELINE RUN (1977 DATA, 20 HR. FLYING PROGRAM) F-CLOCKS BASED ON 1977 HISTORICAL FAILURES/SORTIE.
  - SERIES 1 VALIDATION EXPERIMENTS. F-CLOCKS OF NETWORKS TESTED ARE BASED ON METRICS MODELS WITH 1977 BITBURG OPERATING POINT.
    - EXPERIMENT 1: ALL AVIONICS AND PROPULSION NETWORKS TESTED.
      - EXPERIMENT 2: LARGE DIFFERENCE (METRICS TO BASELINE F-CLOCK VALUES) NETWORKS TESTED.
        - EXPERIMENT 3: ENGINE NETWORKS #1 AND #2 tested.
        - EXPERIMENT 4: ALL AVIONICS NETWORKS TESTED.
          - EXPERIMENT 5: ENGINE #1 NETWORK METRIC TESTED SINGLY.
          - EXPERIMENT 6: FLIGHT INDICATOR F-CLOCK METRIC TESTED.
          - EXPERIMENT 7: UHF SET F-CLOCK METRIC TESTED.
          - EXPERIMENT 8: ATTITUDE-HEADING REF. SET F-CLOCK METRIC TESTED.
          - EXPERIMENT 9: INERTIAL NAV SET F-CLOCK METRIC TESTED.
          - EXPERIMENT 10: AIR DATA SYSTEM F-CLOCK METRIC TESTED.
          - EXPERIMENT 11: HORIZONTAL SITUATION INDIC. F-CLOCK METRIC TESTED.
          - EXPERIMENT 12: AUTOPILOT F-CLOCK METRIC TESTED.
          - EXPERIMENT 13: TACAN SET F-CLOCK METRIC TESTED.
          - EXPERIMENT 14: IFF TRANSPONDER SET F-CLOCK METRIC TESTED.

FIGURE 22 TASK VIII - INITIAL VALIDATION EXPERIMENTS SIMULATION PLAN

Three subsequent series of LCOM simulation experiments were performed to evaluate all thirty F-clock estimation equations within the context of the KC-135A, an aircraft type (cargo-tanker) and subsystem assemblage which was quite different than the baseline aircraft subsystem configuration around which the equations were originally developed, i.e., the F-15A fighter-interceptor. Also, the experiments pertained to Air Force base simulations (Loring, Seymour-Johnson, and Castle) which were not included in the original study data base. Application to these bases forms a significant check on the applicability of the equations to new basing situations and gives indication of the relevant range of the derived F-clock estimation models. Figure 23 presents the simulation plan for the KC-135A/Loring experimental series. The Seymour-Johnson and Castle simulation plans were identical to the one shown.

As in the initial series of experiments, the objective of these simulations was to determine the expected accuracy and confidence level to be placed on estimates computed from the new metrics models when used in a new situation or for an emerging weapon system. The validation experiments were planned to exercise the KC-135A/Loring, Seymour-Johnson, and Castle LCOM simulations with the new F-clock values to test the sensitivity of the simulation results to the metrics inputs. The results of these simulations were then compared to baseline model runs and to actual historical 1977 performance data from the subject bases as discussed in subsection 8.5. As depicted in Figure 23, three simulation runs, each using a different clock control random number seed, were executed for each set of standard, baseline, and metrics validation runs. The code names of these runs are shown on the simulation plan. The three runs for each set were necessary to average out random deviations in the simulation outputs and allow a more accurate comparison of results. The depicted plan was meant to be progressive depending upon the results obtained from the initial experiments in the series. For instance, if the results of experiment 1 (refer to Figure 23), where all 30 F-clocks are modified and tested together, indicate no significant deviations from the historic performance data to be used for comparison, further experimentation would not be required. If, however, significant deviation was detected, then further experimentation according to the plan would be required to identify the particular F-clocks causing the deviation. The actual results of experiment 1 for all three base simulations showed low deviations so in all three cases the optional experiments were not executed.

Reference 18 contains detailed descriptions of the execution and results of the various experimental series. Summary results are presented in subsection 8.5.

MODEL USED--ASD STANDARD LCOM SIMULATION OF KC-135A/LORING AFB
SEYMOUR JOHNSON AFB/CASTLE AFB (1977 DATA BASE)

SERIES 2 COMPARISON RUNS

STANDARD RUNS- LORING AFB (1977 DATA, 7,481 HR. FLYING PROGRAM) F-CLOCKS SET AT STANDARD KC-135A VALUES. (LSEED1, LSEED2, LSEED3)

BASELINE RUNS- F-CLOCKS SET AT LORING BASELINE VALUES. (LSEED7, LSEED8, LSEED9)

SERIES 2 VALIDATION EXPERIMENTS. KC-135A/LORING AFB 1977 OPERATING POINT. F-CLOCKS OF NETWORKS TESTED OBTAINED FROM METRICS MODELS.

EXPERIMENT 1: ALL 30 STUDY NETWORKS TESTED. (LSEED4, LSEED5, LSEED6)

EXPERIMENT 2: LARGE DIFFERENCE (METRICS TO STANDARD F-CLOCK VALUES) NETWORKS TESTED.

OPTIONAL FOLLOW-ON EXPERIMENTS

EXPERIMENT 3: AVIONICS NETWORKS TESTED.

EXPERIMENT 4: PROPULSION NETWORKS TESTED.

EXPERIMENT 5: AIRFRAME NETWORKS TESTED.

EXPERIMENT 6: FLIGHT CONTROL SYSTEMS NETWORKS TESTED.

EXPERIMENT 7: UTILITY SYSTEMS NETWORKS TESTED.

FIGURE 23 TASK VIII - KC-135A/LORING AFB VALIDATION EXPERIMENTS SIMULATION PLAN

8.5 DIFFERENCE ANALYSIS - BASELINE VERSUS MODIFIED MODEL RESULTS (NEW METRICS) - SUBTASK 8.5

As the series of validation experiments were performed, difference analyses were performed which compared the results of the baseline simulations of the subject bases with the various experimental runs. In the case of the KC-135A runs, these simulation results were also compared with actual historical squadron performance data from the 1977 time period simulated. These analyses indicated how well the F-clock values based on estimated metrics data could simulate the actual historic situation as compared to the current standard F-clock values used in the baseline simulations. The analyses compared critical output variables of the baseline runs against the same outputs of the various experimental runs. Table 23 lists the twenty-five critical output variables monitored.

At the conclusion of the initial Phase I validation experiments, a difference analysis was performed which compared the results of the baseline simulation with the various experimental runs as listed in Figure 22. This analysis determined how well the F-clock values based on estimated data could duplicate simulation results from F-clock values based on actual historical data.

In the initial series of Phase I validation runs, it was found that the new F-clock estimating equations developed for the eleven avionic systems were able to duplicate actual historical results within approximately plus or minus 10 percent. It is therefore considered that these estimators can be used for predicting F-clock values in new situations with a high degree of confidence.

The F-clock estimating equation for the propulsion system yielded significant deviations in simulation results compared to the baseline run. Therefore, it was considered that this estimating equation required modification and/or refinement before it can be used with confidence.

As the series of KC-135A validation experiments were performed, difference analyses were performed which compared the results of the baseline simulations of the three subject bases, Loring, Seymour-Johnson, and Castle with the various experimental runs as depicted in Figure 23. These simulation results were also compared with actual historical squadron performance data from the 1977 time period simulated. These analyses indicated how well the F-clock values based on estimated metrics data could simulate the actual historic situation as compared to the current standard F-clock values used in the baseline simulations. The analyses compared the critical output variables (see Table 23) of the baseline runs against the same outputs of the various experimental and standard runs. Selected operational and maintenance (O&M) critical output variables from the baseline runs were then compared against actualy 1977 values from the historic data files from the subject bases in the G033B and D056E Air Force data systems. Figure 24 depicts the relationships of the comparisons made. Summary findings of these difference analyses are presented in Table 24.

TABLE 23

CRITICAL OUTPUT VARIABLES MONITORED

1. PERCENT SORTIES ACCOMPLISHED
2. PERCENT AVAILABLE AIRCRAFT DAYS IN SORTIE
3. PERCENT AVAILABLE AIRCRAFT DAYS IN UNSCHEDULED MAINTENANCE
4. PERCENT AVAILABLE AIRCRAFT DAYS IN SCHEDULED MAINTENANCE
5. PERCENT AVAILABLE AIRCRAFT DAYS IN NOT OPERATIONALLY READY - SUPPLY (NORS)
6. PERCENT AVAILABLE AIRCRAFT DAYS IN MISSION WAIT STATUS.
7. PERCENT AVAILABLE AIRCRAFT DAYS IN SERVICE AND WAITING
8. PERCENT AVAILABLE AIRCRAFT DAYS OPERATIONALLY READY
9. AVERAGE AIRCRAFT POST SORTIE TIME (HOURS)
10. FLYING HOURS ACCOMPLISHED
11. PERCENT AVAILABLE MANHOURS UTILIZED
12. ACTUAL MANHOURS USED
13. PERCENT MAINTENANCE MANHOURS IN UNSCHEDULED MAINTENANCE
14. PERCENT MAINTENANCE MANHOURS IN SCHEDULED MAINTENANCE
15. MAINTENANCE MANHOURS PER FLYING HOUR
16. NUMBER OF REPARABLE GENERATIONS
17. PERCENT BASE REPAIR
18. PERCENT DEPOT REPAIR
19. AVERAGE BASE REPAIR CYCLE
20. PERCENT ACTIVE REPAIR
21. PERCENT WHITE SPACE
22. NUMBER OF ITEMS BACKLOGGED
23. NUMBER OF UNITS DEMANDED
24. PERCENT OF DEMANDS NOT SATISFIED
25. NUMBER OF ITEMS ON BACKORDER

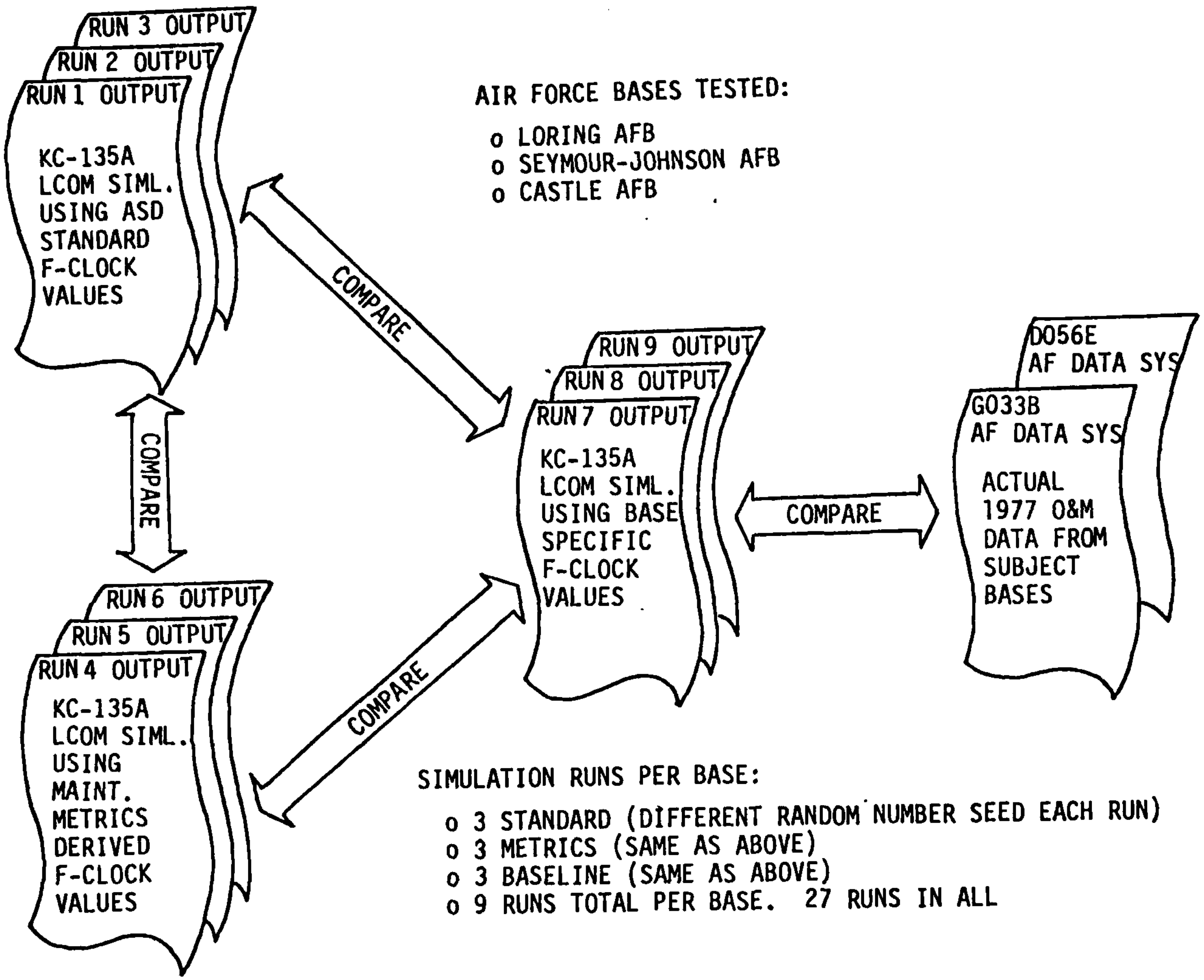

FIGURE 24 RELATIONSHIPS AND PROCEDURE FOR KC-135A METRICS VALIDATION COMPARATIVE ANALYSIS

TABLE 24

SUMMARY FINDINGS FOR KC-135A METRICS VALIDATION EXPERIMENTS

	Average percent difference of the 25 selected critical output variables from 1977 baseline simulated values was --	
	Using ASD Std Failure Clocks	Using Maint. Metrics Derived Failure Clocks
Loring AFB:	- 2.39%	- 2.85%
Seymour-Johnson AFB:	- 8.26%	- 8.93%
Castle AFB:	+ 1.02%	- 2.79%

Seven critical) and M performance parameters were selected for comparison, i.e. --

- o Flying Hours Per Aircraft Per Year
- o Sorties Per Aircraft Per Year
- o Average Operational Ready Rate
- o Average Not-Operationally-Ready-Maintenance Rate
- o Average Not-Operationally-Ready-Supply Rate
- o Total Maintenance Manhours Per Aircraft Per Year
- o Average Maintenance Manhours Per Flying Hour

The average percent deviation of these parameters as simulated by the baseline series runs of the KC-135A LCOM were as follows:

Loring AFB:	-	7.45%	average deviation
Seymor-Johnson AFB:	-	9.57%	
Castle AFB:	-	14.08%	

The comparative analyses of the outputs of the standard and metrics simulation runs against the baseline runs checked the success of the new metrics in simulating base-specific situations. The overall findings of these analyses indicated that the newly developed maintenance metrics were approximately equal to the ASD developed standard KC-135A metrics in producing simulation results similar to the base-specific metrics used in the baseline runs. Both types produced simulated outputs that were generally within 3% of the baseline outputs for Loring and Castle AFB's, and within 9% for Seymour-Johnson AFB. These deviations were considered well within the range of acceptability for most applications of the KC-135A LCOM simulation.

The comparisons of the outputs of the baseline simulation runs with actual 1977 O&M histories at the subject bases measured the overall fidelity of the KC-135A LCOM with the ASD standard input module (except for F-clock values) in reproducing actual base conditions. These comparisons indicated acceptable levels of deviation between the LCOM outputs and actual 1977 field data. The average deviations of the selected O&M parameters were under 10% for Loring and Seymour-Johnson AFB's, and under 15% for Castle AFB (see Table 14).

Since the results of the Validation Experiment 1 runs as discussed above showed such low deviations, the optional follow-on experiments shown on the validation plan of Figure 23 were not performed.

Reference 18 contains complete detailed discussions and data of the results of the various difference analyses.

9.0 SUMMARY CONCLUSION

9.1 SYNOPSIS

This report is the final in a series of five technical reports which document the results of an eight task study to develop new maintenance metrics to aid in forecasting the resource damands of weapon systems. It presents descriptions of methodologies and findings recommended for application to the readiness analysis and resource loading of emerging Air Force weapon systems and basing concepts. Recommended methodologies and findings contained within this final report include: 1) Review of Published Literature; 2) Critical Equipment Selection; 3) Maintenance Impact Parameter Identification; 4) Data BAse Assembly and Integration; 5) Maintenance Impact Estimating Relationship Detection and Analysis; 6) Maintenance Metric Model Development; and 7) Maintenance Metrics Validation. The methodologies and findings contained within this final report are presented in logical functional/sequential flow formats and represent the results of the research approaches and "lessons learned" during the implementation and completion of this AFHRL study effort.

9.2 PROBLEMS, ASSUMPTIONS, AND UNCERTAINTIES

Only one significant problem was encountered during the study. This was the inevitable problem of long lead times between request and receipt of certain types of data such as Air Force weather summaries. This problem was anticipated, however, and the study work schedule designed to accommodate possible data delays. These workarounds were successful and all intended work was accomplished on schedule. Reference 12 contains a detailed discussion of this problem.

Certain assumptions and uncertainties were inherent in the regression procedures used to develop the maintenance metrics models. These were:

(1) The assembled data were accurate and unbiased.

(2) Each data case value was a member of a continuous normal distribution of possible values for that data case (a necessary condition for least squares regression).

(3) Each major independent variable appearing in each metrics model equation is unrelated to the other major independent variables in the model.

(4) The range of values represented by the nine case data samples used encompassed essentially the full range of possible Air Force-wide values for equipment, operational, and environmental characteristics.

The last assumption deals with sufficiency of data. This uncertainty is present in every statistical analysis. A minimum of thirty cases is preferred for high confidence in unbiased results. However, the rather sparse nine case sample used in this study should still produce estimation and prediction results which improve on present methods of predicting the maintenance demands of new weapon systems and/or basing concepts. Reference 17 contains a detailed discussion of the above assumptions and data range uncertainty.

9.3 RECOMMENDATIONS

The following recommendations are provided as a guide to application and follow-on studies using the developed methodologies.

(1) The data base assembled during study tasks one through four contains a wealth of organized data that will be useful for logistic, operations, and environmental analyses for aircraft. The data are also useful for comparability analyses of emerging weapon systems.

(2) The maintenance impact estimating relationships developed in task five are immediately applicable to the identification and quantification of the design, operational, environmental, and maintenance factors which impact the maintenance of aircraft equipment.

(3) The maintenance metrics estimating models developed in tasks six and seven are easy to use and are in a form that facilitates immediate application to maintenance resource predictions for new aircraft equipment, new bases for existing aircraft, new operational scenarios, and LCOM simulation studies.

(4) In addition, the developed metrics will be useful in Air Force manpower determination studies, cost of ownership studies, design trade studies for future aircraft, and readiness determination studies.

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GLOSSARY OF ABBREVIATIONS

AB	Air Base
ACFT	Aircraft
AFB	Air Force Base
AFHRL	Air Force Human Resources Laboratory
AFMEA	Air Force Management Engineering Agency
AGE	Aerospace Ground Equipment
AMS	Avionics Maintenance Squadron
AVG	Average
BIT	Built In Test
BMW	Bomb Wing
CU	Cubic
EAC	Experience Analysis Center
EMAD	Estimate of Maintenance Action Demand
ENVIRON	Environment
EQUIP	Equipment
F-CLOCK	Failure Clock
FOD	Foreign Objects Damage
FT	Feet
FTW	Fighter Training Wing
HF	High Frequency
HR	Hour
HRS	Hours
IFF	Identify Friend or Foe
I/O	Input/Output

LB's	Pounds
LCOM	Logistic Composite Model
MAC	Military Airlift Command
MAINT	Maintenance
MAW	Military Airlift Wing
MH	Manhour
MIER	Maintenance Impact Estimating Relationship
MIN	Minute
MMH	Maintenance Manhour
MMM	Maintenance Manpower Model
MO	Month
MRD	Maintenance Resource Demand
NO	Number
NORM	Not Operational Ready Maintenance
NORS	Not Operational Ready Supply
OCALC	Oklahoma City Air Logistics Center
OPNL	Operational
OR	Operational Ready
ORG	Organization
O&S	Operations and Support
SAALC	San Antonio Air Logistics Center
SAC	Strategic Air Command
SPSS	Statistical Package for the Social Sciences
SRU	Shop Removable Unit

TAC	Tactical Air Command
TACAN	Tactical Air Navigation
TFW	Tactical Fighter Wing
TO	Technical Order
TR	Technical Report
TTW	Tactical Training Wing
UHF	Ultra High Frequency
USAFE	United States Air Forces Europe
WUC	Work Unit Code
WT	Weight

APPENDIX A

METRICS CATALOG DATA ENTRY FORM

METRICS CATALOG DATA ENTRY FORM

The following enumerates the title, contents, and purpose of the field as shown in Figure A-1. Since the alpha character preceeding each field is only used by the computer for identification of that field, it will not be included with the title.

DOC - This is the sequential accession number assigned by EAC investigators for tracking and retrieval purposes.

TITLE - Document title.

PERSONAL AUTHOR - Originator of the document.

DOC NO. - Document number.

FORM - The actual physical form of the document, i.e., hard copy, magazine, microfiche, etc.

SOURCE - The name of the company or government agency from whom the document was obtained or ordered from.

*/DOC $HIST___________

*$T (Title)

$PA (Personal Author)

$DN (Doc. No.)

*$F FORM

Forms
Tech. Reports
Documents/Guide
Briefs/Papers
News Release
Magazine
Computer Tape
List/Index
Card Deck
Microfiche
Brochure
Tech. Data
Book
Logs
Summary

*$L (Source)

$S TYPE OF DATA

Human Resources
Manpower
Skill Level
Experience
Training
Costs
Task Analysis

Material Resources
Spares
Consumable Materiels
AGE
Training Equipment
Test Equipment
POL
Modifications/TCTO
Kits
Costs

Operations Data
Utilization
Sorties
Landings
Inventory/(No. Acft.)
Turn Around
Aborts
Availability
Dependability

Maintenance Data
Organizational Level
Intermediate Level
Depot Level
Vendor
Manhours
Task Analysis
Modifications/TCTO

Reliability Data
Failure Rates
Failure Distribution
Failure Modes
Cost

Safety Data
Accidents/Incidents
Cost

Cost Data
Human Resources
Material Resources
Actuals
Estimates

$P PHASE

Conceptual
Validation
Development
Production
Operation

$NR (Number Reports)___________

$BD (Order Date)______________

$CD (Received Date
Pseudo)______________

$B FILED

EAC MECCA
BAC Kent Library
BCAC Renton Library
BAC Military Publications
METRICS Master File

*$Q QUALITY OF DATA

Source Listing
Screened Documents
Useable
Not Used

$X Address

$D Published

$A

FIGURE A-1 METRICS CATALOG DATA ENTRY FORM

TYPE OF DATA - Seven major areas, each with several sub-areas, are identified to categorize the contents of each document.

PHASE - That particular phase of life the contents of the document covers.

NUMBER REPORTS - Applicable to listings/indexes as to the number of documents contained therein.

ORDER DATE - The date a document was ordered from the source.

RECEIVED DATE PSEUDO - A fictitious date utilized by the computer to indicate all documents ordered but not received.

FILED - An internal study requirement to specify the location of a document.

QUALITY OF DATA - An internal study requirement to distinguish between listings/indexes/bibliographies, reviewed documents, and whether the information was of use to this study.

ADDRESS - Source address.

PUBLISHED - Document publish date.

ABSTRACT - If the contents of a document reviewed did not contribute to any area within the study, an abstract was written for informational purposes.

APPENDIX B

BASE VISIT - AUTHORIZATION LETTER

To: Headquarters Strategic Air Command
Attn: LGM
Offutt Air Force Base, Nebraska 68113

25 April 1978
In Reply Refer To
2-3552-0078-032

Subject: Air Force Contract F33615-77-C-0075, "Development of Maintenance Metrics to Forecast Resource Demands on Weapon Systems" (METRICS)

Contract Monitor:
Mr. Frank Maher
AFHRL/ASR
WPAFB, Ohio 45433
PH (513)255-3771

Contract Manager:
Mr. George R. Herrold
Boeing Aerospace Co.
M/S 4A-45, P.O. Box 3999
Seattle, Washington 9812·
PH (206)655-1941

INTRODUCTION: The Boeing Aerospace Company is performing a study for the Air Force to develop maintenance metrics to forecast resource demands of operational and new development aircraft.

OBJECTIVE: This research is designed to determine how hardware, operational, and environmental parameters impact maintenance demands on aircraft. More accurate METRICS (hardware [measures] and operational and environmental [weightings]) will be developed for incorporation into the Air Force method (Logistics Composite Model [LCOM]) of determining maintenance resource demands.

ASSISTANCE REQUIRED: In compliance with the subject contract, authorization is requested to visit the maintenance organization of the following bases to obtain applicable aircraft operational and maintenance type data. Specific data categories and elements will be coordinated with the various points of contact prior to visit.

BASE	DESIRED DATE (LENGTH OF VISIT)
Fairchild AFB (B-52/KC-135 Wing)	June 26, 1978 (2 days)
Plattsburgh AFB (FB-111 Wing)	June 29, 1978 (2 days)

Gordon A. Eckstrand

Dr. Gordon A. Eckstrand
Director: Advanced System Division (AFHRL/AS)
Air Force Human Resources Laboratory
Wright-Patterson AFB, Ohio

George R. Herrold

George R. Herrold
Contract Manager
Boeing Aerospace Co.
Seattle, Washington

APPENDIX C

BASE VISIT - DATA ACQUISITION
QUESTIONNAIRE

EXAMPLE

WUC'S

NOTE: The complete avionics questionnaire form contained 25 equipment related questions Reference 12 Boeing Interim Technical Report D194-10089-1 contains a complete set of the questionnaire forms utilized in the study.

1. NATIONAL STOCK NUMBER AND/OR PART NUMBER? (QUICK REFERENCE LIST? YES OR NO)

2. LOCATION OF EQUIPMENT ON AIRCRAFT?

3. NUMBER OF EQUIPMENT (QPA) IN AIRCRAFT?

4. EQUIPMENT WEIGHT?

APPENDIX D

GENERIC MAINTENANCE METRICS MODELS

TABLE D1 EQUIPMENT CHARACTERISTICS MAINTENANCE METRICS MODELS

MAD PER UE PER YEAR = F(EQUIPMENT PARAMETERS)

PROPULSION SYSTEM MAD	= -44.142+0.421(P02)+0.192(P04)
FLIGHT INDICATORS MAD	= -0.557+0.720(A03)
AIR DATA SYSTEM MAD	= +8.271+0.155(A03)-1.680(A07)-0.298(A16)-0.054(A19)
HSI SET MAD	= +4.643-1.076(A07)-0.296(A16)+0.0065(A18)
AUTOPILOT MAD	= +39.196-1.163(A03)+0.032(A04)-2.885(A08) -3.698(A13)-0.262(A19)
UHF COMM SET MAD	= -3.131+3.418(A03)-0.081(A04)-1.562(A05)
IFF TRANSPONDER MAD	= +1.147+0.377(A02)-0.0185(A09)
INS SET MAD	= -0.034+0.346(A05)
ILS SET MAD	= -0.456+0.200(A02)+0.011(A06)+0.043(A15)
TACAN SET MAD	= +0.366+0.174(A03)-0.159(A18)
A-H REF SET MAD	= +6.371-1.022(A08)-0.074(A12)
RADAR SET MAD	= -139.80-5.896(A02)+0.211(A12)+1.837(A19)

(SHEET 1)

TABLE D1 CONTINUED

RADOME MAD	= -0.16+0.2988(F08)
WINDSHIELD MAD	= +73.211+0.0069(F03)-0.7321(F07)
WINGS MAD	= -2.8658+0.0263(F04)
SEATS MAD	= -0.4209+0.008(F11)
MAIN LANDING GEAR MAD	= -0.834+0.002(F03)+1.126(F06)+ +4.505(F13)-0.021(F22)
BRAKES MAD	= +6.6688-0.0598(F09)
STABILATOR MAD	= -4.7109+0.0032(F03)+0.9834(F06)
RUDDER MAD	= None
FLAPS MAD	= -10.1007+0.0099(F03)-0.0082(F04) +2.2542(F06)-0.2792(F08)+2.6026(F10)
WATER SEPARATOR MAD	= -0.0517+0.1196(F08)
GENERATOR ASSY MAD	= +0.1755 +1.0992(F13)

(SHEET 2)

TABLE D1 CONTINUED

ANTI-COLLISION LIGHTS MAD	= +1.1342+0.2321(F03)-0.4572(F06)
LANDING/TAXI LIGHTS MAD	= -1.4892+0.2112(F03)+32.8196(F13)
HYDRAULIC PUMPS MAD	= +0.8148+0.0009(F04)-0.0630(F11)
FUEL TANKS MAD	= -1.7168+0.6864(F16)
OXYGEN REGULATOR MAD	= +1.4902-0.4519(F03)
LOX CONVERTER MAD	= -0.336+0.1324(F08)
ENGINE FIRE DETECTION MAD	= +0.0686-0.0322(F04)+0.0093(F08)

(SHEET 3)

TABLE D2 OPERATIONAL CHARACTERISTICS MAINTENANCE METRICS MODELS

MAD PER UE PER YEAR = F(OPERATIONAL PARAMETERS)

PROPULSION SYSTEM MAD	= -73.317+0.034(Ø10)-1.013(Ø14)+0.303(Ø27) +11.756(Ø32)+25.771(Ø33)
FLIGHT INDICATORS MAD	= -17.267+0.003(Ø11)+0.002(Ø13)+0.0086(Ø17) +0.020(Ø25)
AIR DATA SYSTEM MAD	= +4.628-0.0017(Ø08)+0.0013(Ø13)-0.312(Ø23)
HSI SET MAD	= +1.378+0.036(Ø14)-0.615(Ø33)
AUTOPILOT MAD	= +7.294-0.0015(Ø08)+0.388(Ø23)
UHF COMM SET MAD	= +10.022-0.002(Ø08)+0.910(Ø13)
IFF TRANSPONDER MAD	= +14.439+0.260(Ø05)-0.017(Ø09)-0.119(Ø12)-0.706(Ø30)
INS SET MAD	= -10.681+0.004(Ø13)
ILS SET MAD	= -0.035+0.0024(Ø15)-0.0044(Ø27)-0.0025(Ø32)
TACAN SET MAD	= -2.056+0.0074(Ø15)+0.425(Ø32)
A-H REF SET MAD	= -13.778+0.112(Ø05)
RADAR SET MAD	= +12.669+0.006(Ø10)-0.0045(Ø11)

(SHEET 1)

TABLE D2 CONTINUED

RADOME MAD	= -10.099+0.104(Ø05)-0.051(Ø12)+0.0062(Ø21) +0.0046(Ø25)
WINDSHIELDS MAD	= +2.6135-0.0056(Ø15)+0.0400(Ø21)-0.0463(Ø27)
WINGS MAD	= +94.2723+0.2681(Ø02)-0.0113(Ø08)+0.0078(Ø10) -0.4550(Ø12)-0.1245(Ø14)-0.0382(Ø17)+0.1199(Ø21)
SEATS MAD	= -2.0778+0.0005(Ø08)+0.0129(Ø12)+0.0032(Ø17) +0.0168(Ø21)-0.0043(Ø25)-0.0307(Ø27)
MAIN LANDING GEAR MAD	= -5.1619+0.0021(Ø10)+2.2407(Ø14)-0.0211(Ø15) +0.0343(Ø16)+0.0218(Ø19)+0.0368(Ø21)-4.6455(Ø32)
BRAKES MAD	= -12.007+2.1964(Ø03)+0.077(Ø05)+0.0059(Ø09) +0.0046(Ø16)-0.0023(Ø20)+0.0138(Ø26)-0.001(Ø31)
STABILATOR MAD	= +1.5652+0.0361(Ø21)-0.0447(Ø27)
RUDDER MAD	= -0.4337+0.0039(Ø15)-0.0015(Ø17)-0.6222(Ø34)
FLAPS MAD	= +13.1908-0.0313(Ø15)+0.1853(Ø21)-0.2099(Ø27)
WATER SEPARATOR MAD	None
GENERATOR ASSY MAD	= -1.7639+0.023(Ø07)+0.0817(Ø32)

(SHEET 2)

TABLE D2 CONTINUED

ANTI-COLLISION LIGHTS MAD	= +9.3845-0.0022(Ø11)+0.0079(Ø21)-0.0061(Ø25) -0.0201(Ø27)
LANDING/TAXI LIGHTS MAD	= +3.3516-0.0071(Ø15)±0.0522(Ø21)-0597(Ø27)
HYDRAULIC PUMPS MAD	= -1.7478+0.0167(Ø05)+0.0001(Ø06)-0.0002(Ø08) +0.0021(Ø14)-0.1828(Ø32)+0.1715(Ø33)
FUEL TANKS MAD	= +7.8102+0.0014(Ø10)-0.0012(Ø11)-0.0172(Ø15) +0.0145(Ø17)+0.0311(Ø21)-0.0646(Ø27)
OXYGEN REGULATOR MAD	= -0.0196+0.3685(Ø30)
LOX CONVERTER MAD	= -2.041+0.0147(Ø05)-0.0001(Ø06)+0.282(Ø33)
ENGINE FIRE DETECTION MAD	= None

(SHEET 3)

TABLE D3 ENVIRONMENTAL CHARACTERISTICS MAINTENANCE METRICS MODELS

MAD PER UE PER YEAR = F(ENVIRONMENTAL PARAMETERS)

PROPULSION SYSTEM MAD	= +99.239-1.883(E13)
FLIGHT INDICATORS MAD	= -7.598-0.008(E03)+0.104(E19)
AIR DATA SYSTEM MAD	= -7.571-0.132(E13)+0.146(E19)-0.071(E20)
HSI SET MAD	= -5.866-0.074(E13)+0.039(E18)+0.097(E20)
AUTOPILOT MAD	= +12.681+0.474(E08)-0.057(E18)
UHF COMM SET MAD	= -2.359-0.258(E13)-0.089(E18)+0.118(E19) -0.039(E27)+7.457(E30)
IFF TRANSPONDER MAD	= +2.930+0.012(E06)-0.0535(E09)+0.0042(E31)
INS SET MAD	= -2.203+2.447(E21)
ILS SET MAD	= -0.031+0.025(E20)
TACAN SET MAD	= +0.875+0.007(E03)-0.022(E09) -0.0596(E13)+0.163(E20)
A-H REF SET MAD	= +1.093+0.0255(E27)
RADAR SET MAD	= -17.455-0.233(E13)+0.042(E16) +0.083(E18)+0.284(E20)

(SHEET 1)

TABLE D3 CONTINUED

RADOME MAD	= +5.8181-0.0006(E02)-0.0234(E18)+0.0192(E20)
WINDSHIELD MAD	= +15.5688-0.0722(E18)
WINGS MAD	= -0.5229-0.3386(E13)+1.032(E20)
SEATS MAD	= -3.0919+0.0216(E19)+0.0462(E20)
MAIN LANDING GEAR MAD	= +2.0616+0.3565(E20)
BRAKES MAD	= +0.0304-0.0026(E03)+0.0067(E16)
STABILATOR MAD	-2.8538+0.1942(E20)
RUDDER MAD	= -2.6783-0.0023(E03)-0.0038(E09)+0.0136(E18) +0.0614(E24)
FLAPS MAD	= +18.583-0.1954(E18)+0.2366(E19)
WATER SEPARATOR MAD	= -1.249+0.022(E19)-0.0188(E24)
GENERATOR ASSY MAD	= +0.669-0.0093(E13)

(SHEET 2)

TABLE D3 CONTINUED

ANTI-COLLISION LIGHTS MAD	= +11.0074-0.0007(E02)-0.004F(E03)-0.0257(E18) -0.9807(E30)
LANDING/TAXI LIGHTS MAD	= +6.1366-0.0654(E18)+0.0795(E19)
HYDRAULIC PUMPS MAD	= +0.1558-0.01505(E06)+0.252(E08)
FUEL TANKS MAD	= +5.03+0.009(E16)-0.027(E18)+0.035(E19) -0.064(E23)
OXYGEN REGULATOR MAD	= +6.414+0.0099(E06)+0.0412(E07)-0.0026(E16)+ +0.195(E21)-0.0291(E23)-0.0672(E24)-0.0515 (E27)
LOX CONVERTER MAD	= +0.2299+0.0842(E08)
ENGINE FIRE DETECTION MAD	= -0.2536+0.0006(E16)+0.0026(E19)-0.0017(E24)

(SHEET 3)

TABLE D4 DEFINITION OF GENERIC MODELS' PARAMETERS

EQUIPMENT PARAMETERS	OPERATIONAL PARAMETERS	ENVIRONMENTAL PARAMETERS
P02 = TOTAL NO. OF ENGINES	Ø05 = AVG. TAKE-OFF SPEED	E03 = RUNWAY DIRECTION
P04 = WT. PER ENGINE	Ø08 = AVG. CLIMB RATE	E06 = NO. OF SNOW DAYS
A02 = EQUIP. LOCATION ON ACFT.	Ø09 = AVG. CRUISE SPEED	E08 = MEAN SNOW DEPTH
A03 - EQUIP. WT.	Ø10 = AVG. CRUISE ALTITUDE	E09 = NO. RAIN DAYS
A04 - EQUIP. VOL.	Ø11 = AVG. DESCENT RATE	E13 = NO. THUNDER DAYS
A05 = SRU COUNT	Ø12 = AVG. LANDING SPEED	E16 = PREDOMINATE WIND DIRECTION
A06 = OPERATING TEMP.	Ø13 = MIN LANDING DISTANCE	E18 = MAX CROSSWINDS 10-19 MPH DAYS
A07 = COOLING METHOD	Ø14 = AVG. LANDING WT.	E19 = MAX CROSSWINDS 20-29 MPH DAYS
A08 = PROTECTION DEVICES	Ø15 = TOTAL FLT. HR. PER ACFT.	E20 = MAX CROSSWINDS 30-39 MPH DAYS
A09 = NO. OF TEST POINTS	Ø17 = OPS. FLT. HR. PER ACFT.	E21 = MAX CROSSWINDS 40-49 MPH DAYS
A12 = AGE UNRELIABILITY	Ø18 = MISC. FLT. HR. PER ACFT.	E27 = MIN TEMP. BELOW 32°F DAYS
A13 = AVG. OP. TIME PER SORTIE	Ø23 = AVG. NO. ALERT ACFT.	E30 = AVG. VISION OBSTRUCTION TYPE
A15 = RETEST OK RATE	Ø25 = TOTAL SORTIES PER AIRCRAFT	E31 = AVG. OBSTRUCTION SEVERITY
A16 = ON-OFF CYCLES PER FLT. HR.	Ø27 = OPS. SORTIES PER ACFT.	E07 = TOTAL SNOW FALL
A18 = GND/FLT OPERATING RATIO	Ø30 = MAX ACFT. SPEED	E24 = MEAN MIN. TEMP.
A19 = FAILURE/ABORT RATIO	Ø32 = ACFT. CREW SIZE	E23 = MEAN TEMP.
F03 = EQUIP. WT.	Ø33 = AVG. SORTIE LENGTH	
F04 = EQUIP. VOL.	Ø03 = AVG. MISSION MIX	
F06 = SUPPORT EQUIP. COMPLEXITY	Ø06 = MEDIAN TAKE-OFF DISTANCE	
F07 = SUPPORT EQUIP. RELIABILITY	Ø07 = PERCENT OF MAX. TAKE-OFF WT.	
F08 = TYPE OF FAIL. PROBLEMS	Ø19 = TOTAL LANDINGS PER ACFT.	
F09 = IN-FLT SQUAWK VERIF. RATE	Ø21 = OP. LANDINGS PER ACFT.	
F11 = GRD TO FLT OP. RATIO	Ø26 = TRAINING SORTIE PER ACFT.	
F13 = REMOVALS TO ACCESS OTHER EQUIP.	Ø31 = SERVICE ACFT CEILING	
F16 = EQUIP. PROTECTION METHODOLOGY	Ø34 = ACCIDENTS (MAJOR/MINOR) PER ACFT.	
	Ø16 = TRAINING FLYING HR PER ACFT	
	Ø20 = TNG LANDINGS PER ACFT	

APPENDIX E

TABLE E1 COMPOSITE MAINTENANCE METRICS AND WEIGHTINGS MODELS

MAD PER UE PER YEAR = F(EQUIPMENT, OPERATIONAL, & ENVIRONMENTAL PARAMETERS)

PROPULSION SYSTEM MAD	= -57.675+0.244(P02)+0.055(P04)+0.021(Ø10) +0.203(Ø27)-0.798(Ø32)+7.509(Ø33)
FLIGHT INDICATORS MAD	= - 4.658+0.398(A03)+0.00004(Ø13)+0.0016(Ø17) -0.0036(E03)+0.045(E19)
AIR DATA SYSTEM MAD	= - 1.975+0.023(A03)-0.035(A16)-0.0008(Ø08) +0.0005(Ø13)-0.071(Ø23)-0.046(E13)+0.063(E19)
HSI SET MAD	= -14.292+0.751(A07)+1.003(A16)-0.049(Ø14) +3.020(Ø33)+0.177(E20)
AUTOPILOT MAD	= +21.944-0.481(A03)+0.0159(A04)-1.496(A13) -0.258(A19)-0.0004(Ø08)+0.637(Ø23)+0.016(E18)
UHF COMM SET MAD	= -101.62-0.208(A03)+1.011(A05)-0.016(Ø08) +6.732(Ø18)+1.415(E18)+0.419(E19)-60.986(E30)
IFF TRANSPONDER MAD	= + 0.890+0.602(A02)-0.026(A09)-0.813(Ø30) +0.0078(E09)
INS SET MAD	= - 0.034+0.346(A05)
ILS SET MAD	= - 1.128+0.025(A06)+0.0040(Ø15)-0.0074(Ø27) -0.025(E20)
TACAN SET MAD	= - 1.843+0.061(A03)-0.044(A18)+0.099(Ø32) +0.0058(E03)-0.017(E09)+0.142(E20)
A-H REF SET MAD	= -11.435-1.967(A08)+0.155(Ø05)-0.056(E27)
RADAR SET MAD	= -163.53-7.695(A02)+0.209(A12)+2.017(A19) +0.0013(Ø11)+0.271(E13)+0.138(E20)

(SHEET 1)

TABLE E1 CONTINUED

RADOME MAD	= -2.299+0.058(F08)+0.0274(Ø05)+0.0125(Ø21) -0.078(E20)
WINDSHIELD MAD	= +18.2433-0.099(F07)-0.0053(Ø15)+0.0309(Ø21) -0.0371(Ø27)-0.0289(E18)
WINGS MAD	= -27.4212+ .0205(F04)-0.0063(Ø08)+0.5034(Ø12) -0.0962(Ø14)+0.0157(Ø21)-0.3339(E13)+0.2438 (E20)
SEATS MAD	= -4.6375+0.0010(Ø08)+0.0493(Ø12)+0.0086(Ø17)+ +0.024(Ø21)-0.010(Ø25)-0.0538(Ø27)-0.0245 (E19)
MAIN LANDING GEAR MAD	= -3.8152+1.1603(F06)+1.7355(F13)+0.0389(Ø14) +0.0101(Ø19)+0.0013(F03)
BRAKES MAD	= -31.3801+0.1277(F09)+2.0431(Ø03)+0.1902(Ø05) +0.0017(Ø26)-0.0017(Ø31)-0.008(E03)
STABILATOR MAD	= -2.469+0.0023(F03)+0.8617(F06)+0.0141(Ø21)- -0.0872(E20)
RUDDER MAD	= +0.2636+0.0022(Ø15)-1.9625(Ø34)-0.0013(E03)
FLAPS MAD	= +48.3324+0.010(F03)+0.967(F06)-0.618(F08)- -0.023(Ø15)+0.007(Ø27)-0.224(E18)+0.049(E19)
WATER SEPARATOR MAD	= -1.249+0.022(E19)-0.0188(E24)
GENERATOR ASSY MAD	= -1.290+0.904(F13)+0.018(Ø07)

(SHEET 2)

TABLE E1 CONTINUED

ANTI-COLLISION LIGHTS MAD	= +27.614-0.1434(F03)+1.070(F06)-0.010(Ø11)- -0.019(Ø21)-0.038(Ø25)-0.084(Ø27)+3.971(E30)
LANDING/TAXI LIGHTS MAD	= +4.937+0.280(F03)+18.60(F13)-0.006(Ø15)- -0.0498(E18)+0.051(E19)
HYDRAULIC PUMPS MAD	= +1.0089-0.031(F11)-0.0001(Ø08)-0.005(Ø14)- -0.026(Ø32)+0.288(Ø33)+0.013(E06)-0.079(E08)
FUEL TANKS MAD	= +12.353+0.080(F16)+0.0003(Ø10)-0.0078(Ø15)+ +0.0169(Ø21)-0.019(Ø27)-0.060(E18)+0.027(E19)
OXYGEN REGULATOR MAD	= +5.476-0.121(F03)-0.356(Ø30)+0.038(E06)+ +0.026(E07)+0.181(E21)-0.081(E24)-0.065(E27)
LOX CONVERTER MAD	= -2.4302+0.058(F08)+0.016(Ø05)-0.0001(Ø06)+ +0.168(Ø33)
ENGINE FIRE DETECTION MAD	= -0.316-0.006(F08)+0.0006(E16)+0.004(E19)- -0.0017(E24)

(SHEET 3)

TABLE E2 DEFINITION OF COMPOSITE MODELS' PARAMETERS
(SHEET 1)

	P02 = TOTAL NO. OF ENGINES
	P04 = WT. PER ENGINE
	A02 = EQUIP. LOCATION ON ACFT.
	A03 = EQUIP. WT.
	A04 = EQUIP. VOL.
	A05 = SRU COUNT
	A06 = OPERATING TEMP.
	A07 = COOLING METHOD
	A08 = PROTECTION DEVICES
	A09 = NO. OF TEST POINTS
EQUIPMENT	A12 = AGE UNRELIABILITY
PARAMETERS	A13 = AVG. OP. TIME PER SORTIE
	A16 = ON-OFF CYCLES PER FLT. HR.
	A18 = GND/FLT OPERATING RATIO
	A19 = FAILURE/ABORT RATIO
	F03 = EQUIP. WT.
	F04 = EQUIP. VOL.
	F06 = SUPPORT EQUIP. COMPLEXITY
	F07 = SUPPORT EQUIP. RELIABILITY
	F08 = TYPE OF FAILURE PROBLEMS
	F09 = IN-FLT SQUAWK VERIFICATION RATE
	F11 = GRD TO FLT OP. RATIO
	F13 = REMOVALS TO ACCESS OTHER EQUIP.
	F16 = EQUIP. PROTECTION METHODOLOGY
	Ø05 = AVG. TAKE-OFF SPEED
	Ø08 = AVG. CLIMB RATE
	Ø10 = AVG. CRUISE ALTITUDE
	Ø11 = AVG. DESCENT RATE
	Ø13 = MIN LANDING DISTANCE
	Ø14 = AVG. LANDING WT.
	Ø15 = TOTAL FLT. HR. PER ACFT.
	Ø17 = OPS. FLT. HR. PER ACFT.
	Ø18 = MISC. FLT. HR. PER ACFT.
OPERATIONAL	Ø23 = AVG. NO. ALERT ACFT.
PARAMETERS	Ø27 = OPS. SORTIES PER ACFT.
	Ø30 = MAX ACFT. SPEED
	Ø32 = ACFT. CREW SIZE
	Ø33 = AVG. SORTIE LENGTH
	Ø03 = AVG. MISSION MIX
	Ø06 = MEDIAN TAKE-OFF DISTANCE
	Ø07 = PERCENT OF MAX. TAKE-OFF WT.
	Ø19 = TOTAL LANDINGS PER ACFT.
	Ø21 = OP. LANDINGS PER ACFT.
	Ø26 = TRAINING SORTIE PER ACFT.
	Ø31 = SERVICE ACFT CEILING
	Ø34 = ACCIDENTS (MAJOR/MINOR) PER ACFT.
	Ø12 = AVG. LANDING SPEED
	Ø25 = TOTAL SORTIES PER AIRCRAFT

TABLE E2 CONTINUED
(SHEET 2)

ENVIRONMENTAL PARAMETERS	E03 = RUNWAY DIRECTION E09 = NO. RAIN DAYS E13 = NO. THUNDER DAYS E18 = MAX CROSSWINDS 10-19 MPH DAYS E19 = MAX CROSSWINDS 20-29 MPH DAYS E20 = MAX CROSSWINDS 30-39 MPH DAYS E27 = MIN TEMP. BELOW 32°F DAYS E30 = AVG. VISION OBSTRUCTION TYPE E31 = AVG. OBSTRUCTION SEVERITY E07 = TOTAL SNOW FALL E24 = MEAN MIN. TEMP. E06 = NO. OF SNOW DAYS E08 = MEAN SNOW DEPTH E16 = PREDOMINATE WIND DIRECTION E21 = MAX. CROSSWINDS 40-49 MPH DAYS

APPENDIX F

LCOM FAILURE CLOCK
CALCULATION WORKSHEET

EXAMPLE OF FAILURE CLOCK
TRANSFORMATION ROUTINE

EQUIPMENT SUBSYSTEM	SUBSYSTEM WUC	LCOM F CLOCK	MAINT. METRIC MODEL WUC'S	ACTUAL MAINT. ACTION DEMAND PER UNIT PER YEAR					
				LCOM R +	LCOM M +	LCOM H =	TOTAL MAD ÷	NO. UNITS =	AMAD

PARTIAL AMAD (MODEL WUC'S)	PARTIAL ESTIMATED MAINT. ACTION DEMAND (PEMAD) PER UNIT PER YEAR (MAINT. METRIC REGRESSION ESTIMATING MODEL)																	
	A +	(B1 *	X1) +	(B2 *	X2) +	(B3 *	X3) +	(B4 *	X4) +	(B5 *	X5) +	(B6 *	X6) +	(B7 *	X7) =	PEMAD *	$\frac{AMAD}{PAMAD}$ =	TOTAL EMAD

$\frac{AMAD}{EMAD}$ *	PRESENT CLOCK VALUE =	METRIC MODEL ADJUSTED CLOCK

Where: WUC = Work Unit Code
LCOM F Clock = Clock I.D. Number
R = Maintenance Task Code (Remove)
M = Maintenance Task Code (Fix in place)
H = Maintenance Task Code (Check OK)
MAD = Maintenance Action Demand
AMAD = Actual Maintenance Action Demand
Xn = Significant Equipment, Operational, and Environmental Parameters
PEMAD = Partial Estimated Maintenance Action Demand
PAMAD - Partial Actual Maintenance Action Demand
EMAD - Estimated Maintenance Action Demand

LCOM FAILURE CLOCK CALCULATION WORKSHEET

EXAMPLE OF FAILURE CLOCK TRANSFORMATION PROCEDURE:

Assume that there exists a failure clock for the F-15A Flight Indicators Subsystem (WUC-51A) which is based on 1977 maintenance demand and sortie data from Bitburg Air Base.

Step 1 Derivation time period = 1977

Step 2 Actual maint. action demand (AMAD) for WUC-51A:

(LCOM definition AMAD per system per year)
(Source: AFM 66-1 (D056E) data for 1977)

LCOM Task Code R = 46 actions/32 systems = 1.43750
LCOM Task Code M = 20 actions/32 systems = 0.62500
LCOM Task Code H = 11 actions/32 systems = 0.34375
Total 1977 AMAD (LCOM Definition) 2.40625

Step 3 1977 values for significant F-15A (WUC-51A) Maintenance Metrics Regression Model variables (Bitburg data):

Equipment Variables:
A03, Equipment Weight . . . . 0.72 lbs.

Operations Variables:
O13, Minimum Landing Distance . . . . . . .3750.00 feet
O17, Operations Flying Hours per Aircraft . 223.53 hrs./yr.
Environmental Variables:
E03, Runway Direction . . . . 240.00 compass degree
E19, Maximum Crosswinds 20-29 mph . . . . . 106.00 days/yr.

Step 4 Estimated maint. action demand (EMAD) for WUC-51A:
(F-15A Bitburg Situation, 1977)

WUC-51A Maint. Metrics Regress Model:
(Derived from data for WUCs 51AD, 51AH, and 51AK)

EMAD = 4.65791+(0.39813)(0.72)+(0.00036)(3750.0)+...
...+(0.00159)(223.53)-(0.00351)(240.0)+(0.04497)(106.0)
EMAD (for 51AD, 51AH, 51AK) = 1.23458 actions per year
AMAD (for 51AD, 51AH, 51AK) = 0.88 actions per yr (from 66-1 data)
Ratio of total 51A AMAD to partial AMAD above:
2.40625/0.88 = 2.73
Total 51A EMAD = (2.73)(1.23458) = 3.376

Step 5 Ratio of total WUC-51A EMAD to AMAD
3.376/2.406 = 1.403

Step 6 Calculation and transformation of baseline failure clock value:

Assume that the baseline WUC-51 failure clock value is based on sorties per failure for the year 1977 with no allowance for peak sortie rate or peak failure rate periods.

Then--Sorties per Failure = Total Sorties per Acft/Total AMAD per unit
= 174.53/2.406
= 72.54

Set baseline F-clock at 73 sorties to failure
Transformed F-clock value = (AMAD/EMAD) (Baseline Clock Value)
= (1.403)(72.54)
= 101.77

Set new F-clock value at 102 sorties to failure by adding a clock change card to the LCOM control deck designating the appropriate clock number and the new clock value.

THE BOEING COMPANY

ACTIVE SHEET RECORD											
SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
1						47					
2						48					
3						49					
4						50					
5						51					
6						52					
7						53					
8						54					
9						55					
10						56					
11						57					
12						58					
13						59					
14						60					
15						61					
16						62					
17						63					
18						64					
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20						66					
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30						76					
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32						78					
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34						80					
35						81					
36						82					
37						83					
38						84					
39						85					
40						86					
41						87					
42						88					
43						89					
44						90					
45						91					
46						92					